Response of straw-necked ibis (*Threskiornis spinicollis*) to Commonwealth environmental watering in the lower Lachlan, 2015

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Executive Summary

This report (desktop review) was prepared for the Commonwealth Office of Environmental Water to assess the response of straw-necked ibis (*Threskiornis spinicollis*) to Commonwealth environmental watering in the lower Lachlan in 2015.

In response to above average rainfall across the Lachlan catchment in winter 2015, inflows to Wyangala dam exceeded thresholds for planned environmental water (translucent releases) provided under the Lachlan Regulated River Water Sharing Plan in September 2015 (see WSP 2003). In addition, the Commonwealth Environmental Water Holder (CEWH) and NSW Office of Environment and Heritage (NSW OEH) provided environmental flows prior, and subsequent to the translucent event, to provide a slower flow recession. A component of this translucent flow entered the Booligal wetlands where straw-necked ibis were observed in the area exhibiting nest preparation behaviour (trampling of lignum and other nesting vegetation) and environmental water delivery was continued to the site to support an expected breeding event. However, the behaviour of the birds did not continue onto the nest building or egg laying stages. This was unexpected due to the suitability of other environmental conditions. Water levels were maintained at the colony site and vegetation (nesting habitat) condition was reported to be good.

Despite rainfall and flow conditions being favourable in June-September 2015, there were hotter than average temperatures for the region in conjunction with very low rainfall in October at Booligal. The high temperatures and lack of rainfall resulted in a drying off of the surrounding landscape potentially impacting on the availability of food resources. In addition the favourable conditions in the lower Lachlan locally contrasted with generally very dry conditions elsewhere in the Murray-Darling basin.

There were also rapid declines in both flows and water levels measured at Booligal Wetlands during the period over which ibis were observed in the colony area. In addition, total flow volumes were lower than those usually associated with successful colonial waterbird breeding. In addition there were other wetland habitats available nearby in the region, with inundated wetland habitats available in the Lowbidgee Wetlands, the Barmah-Millewa and Great Cumbung Swamp.

The desktop review of hydrology and other environmental conditions for the period of interest (2015) suggest that a combination of factors relating to climate, hydrology, food resources and potentially alternative habitat influenced the decision by ibis not to breed in the Booligal Wetlands in 2015.

Introduction

Breeding opportunities for colonial waterbirds are often triggered by flood events at key wetlands. Forty-six per cent of all wetland sites throughout Australia that are used for colonial waterbird breeding occur in the Murray Darling Basin. Of these, relatively few wetlands (<5% recorded) support large colonial waterbird breeding events (Brandis 2010). The Booligal wetlands in the lower Lachlan catchment are one of the key sites for colonial waterbird breeding in the Murray Darling Basin. The management of environmental water to protect and ensure the ecological capacity for the recovery of waterbird habitat and to support waterbird breeding forms part of the strategic direction for the wetland (Commonwealth of Australia 2016).

In early September 2015 a translucency flow was delivered to the lower Lachlan. Increasing numbers of straw-necked ibis were observed by locals in the lower Lachlan area generally and in the area of the Booligal wetland in particular. In the Booligal Wetlands they were observed exhibiting nest preparation behaviour (trampling of lignum and other nesting vegetation) and environmental water delivery was continued to the site to support an expected breeding event. However, the behaviour of the birds did not continue onto the nest building or egg laying stages. This was unexpected due to the suitability of other local environmental conditions. For example water levels in the Booligal Wetlands reached and were maintained at the level historically associated with ibis breeding (Driver 2005). Similarly vegetation conditions were reported to be healthy (Dyer pers comm. 2015, Appendix 3).

While ibis did not breed during 2015 on the lower Lachlan wetlands, it does provide a unique opportunity to study the reason why ibis did not breed. This desk top study was commissioned to review the hydrology and environmental conditions that may have resulted straw-necked ibis not breeding. Reasons for this may include; weather conditions, declining river flows, availability of food resources and other available habitat e.g. Lower Murrumbidgee. The results of this study will provide information on conditions that may be required for successful ibis breeding in the Booligal and inform future water delivery decisions.

The Booligal Wetlands

The swamps of the Merrowie, Merrimajeel and Muggabah creeks are known collectively as the Booligal Wetlands and encompass between 10 –15,000 ha of the lower Lachlan floodplain (Armstrong et al. 2009). The Booligal Wetland inland floodplain swamp complex includes Booligal Swamp, Upper Gum Swamp, Lower Gum Swamp, Merrimajeel Swamp and Murrumbidgil Swamp.

The Booligal Wetlands consist of low gradient braided channels and cover approximately 5,000 ha when flooded. They are ephemeral wetlands which experience irregular flooding with extended dry periods (Rogers and Ralph 2011).The channels are surrounded by Lignum (*Muehlenbeckia cunninghamii*) shrublands, scattered stands of river red gums (*Eucalyptus camaldulensis)*, black box (*E. largiflorens*) and river cooba (*Acacia stenophylla*). The creeks that flow into the Booligal wetland, Merrimajeel and Muggabah, receive water from the Lachlan River via Torriganny Creek.

Torrigany, Merrimajeel and Muggabah creeks are not included in the areas of operation of the Water Sharing Plan for the Lachlan Regulated River Water Source (WSP). Regulators have been constructed at the mouth of both Muggabah Creek and Merrimajeel Creek to improve water delivery to these creeks and their associated wetlands, and to improve the delivery of replenishment (stock and domestic) flows to water users on the two creeks (http://www.lrwg.com.au/lachlan-river-wetlands/nationally-significant-wetlands-2/booligal-wetlands/).

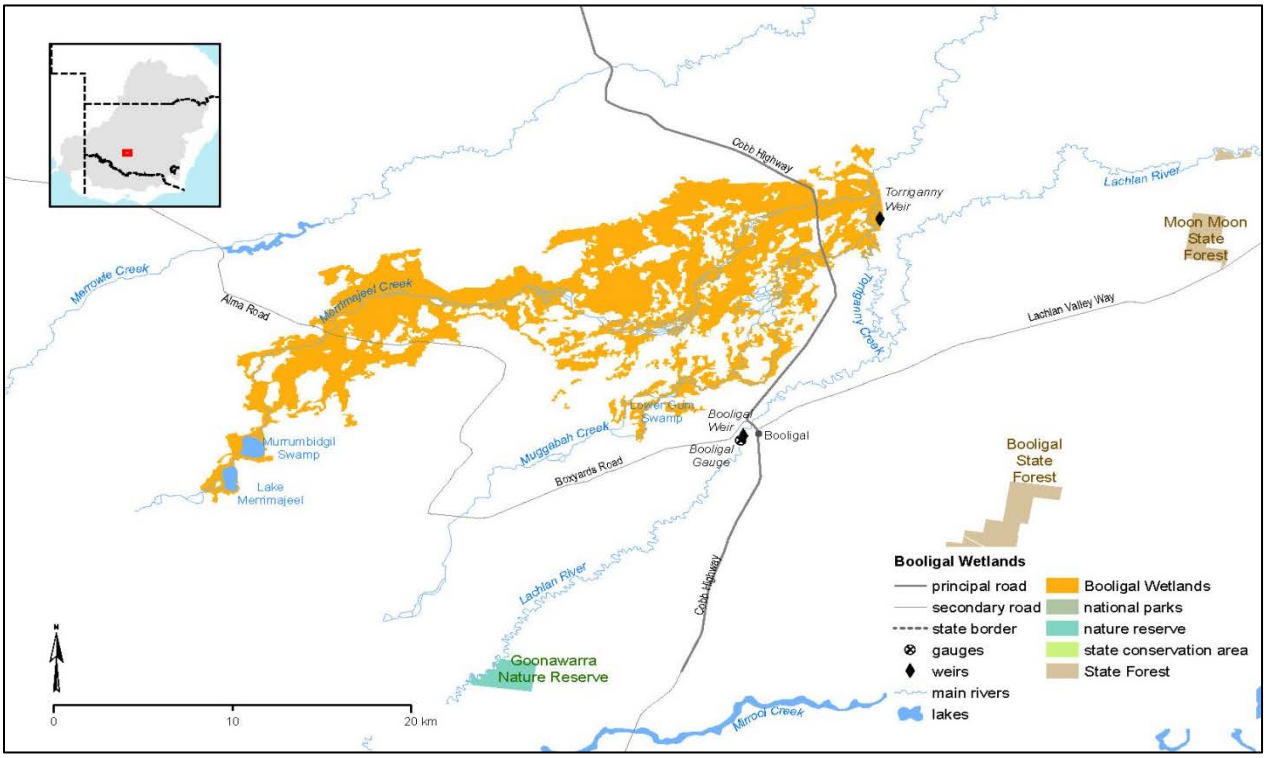


Figure 1 Booligal wetlands, lower Lachlan region of the Lachlan River catchment (source: MDBA 2012).

The Booligal Wetlands are listed on the Directory of Important Wetlands due to key ecological assets such as river red gums, lignum, and waterbird breeding habitat. The maintenance of these key vegetation communities and the provision of flow regimes that is conducive to successful breeding by colonial waterbirds are stated ecological targets for water management (MDBA 2012).

Historical breeding at Booligal Wetlands

Driver et al. (2005) found all colonial waterbird breeding events in Booligal Wetlands (consisting of mostly ibis) recorded since 1984 occurred when flows exceeded 2,500 ML/d at Booligal Weir. The average flood duration for the years where the number of ibis nests was greater than 10,000 was around 111 days. Based on an empirical relationship between the duration of wetland flooding and the size of colonial bird breeding events, flows need to be maintained for 50 days or more to ensure large scale breeding events of greater than 10,000 pairs (Driver et al. 2005).

Table 1 Recorded Straw-necked ibis breeding events at Booligal Wetlands.

Year	Number of ibis nests	Comments	Reference
1984	80,000	Colony failed due to rapid water level drop	Magrath et al. 1991
1989	25,000	Colony failed due to rapid water level drop	Magrath et al. 1991
1990	45,000		Driver et al. 2005
1992	10,000		Driver et al. 2005
1993	40,000		Driver et al. 2005
1996	450		Driver et al. 2005
1998	40,000	Natural flood	Driver et al. 2005
2000	36,000	“Miracle” event, 350GL flow - managed	Driver et al. 2005
2005	10,000	Merrowie Creek colony. Environmental flow 6.65GL	Wettin et al. 2006
2010	75,000		EAWS, 2016

There have been two documented events (Table 1), 1984 (Figure 1) and 1989 (Figure 2) when straw-necked ibis deserted nests due to rapid drops in water levels (Magrath et al. 1991). In 1984 the rapid falls in water and nest desertion by some adults resulted in the construction of a temporary block bank to help stabilise water levels. A permanent block bank was constructed in 1992. The Block bank is an important water management tool and has been used in all waterbird breeding events since 1984 in conjunction with environmental water diversions from Torriganny Weir (Barma Water Resources et al. 2011).

Despite the ability to stablise water levels at the Block bank colony site, the two recorded nest desertion events were associated with rapid falls in flows. Hydrological data is not available for Merrimajeel at Block bank for these time periods and therefore analyses of flows closer to the traditional colony site cannot be done. However we can examine flows at Booligal for these two time periods (Figure 1 & Figure 2).

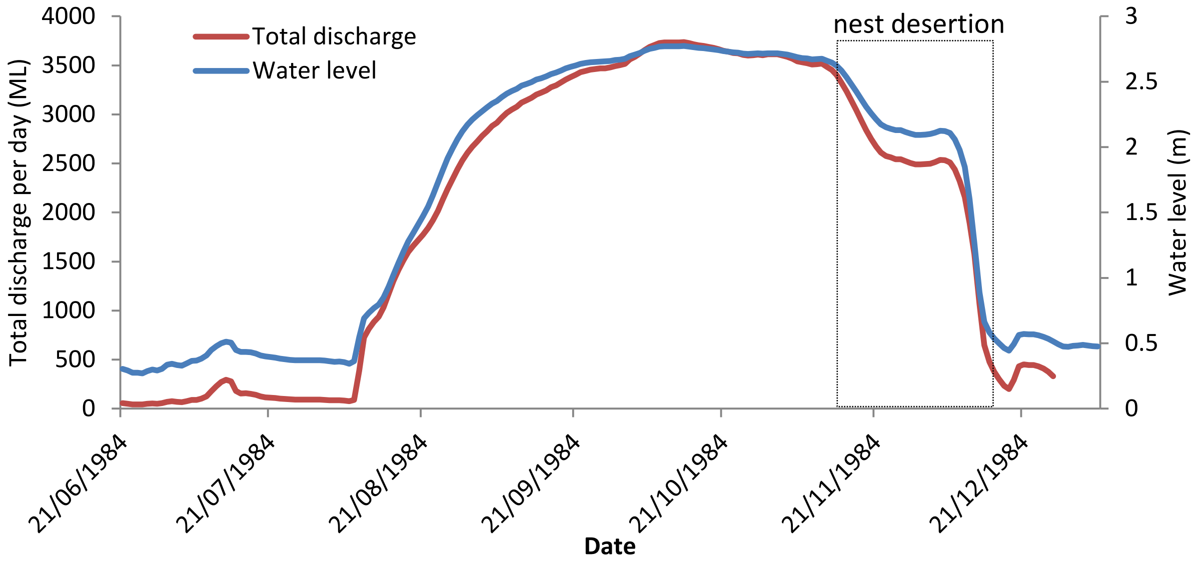


Figure 2 Daily flows and water levels at Booligal June – Dec. 1984 with period of ibis breeding (dashed box) and nest desertion identified.

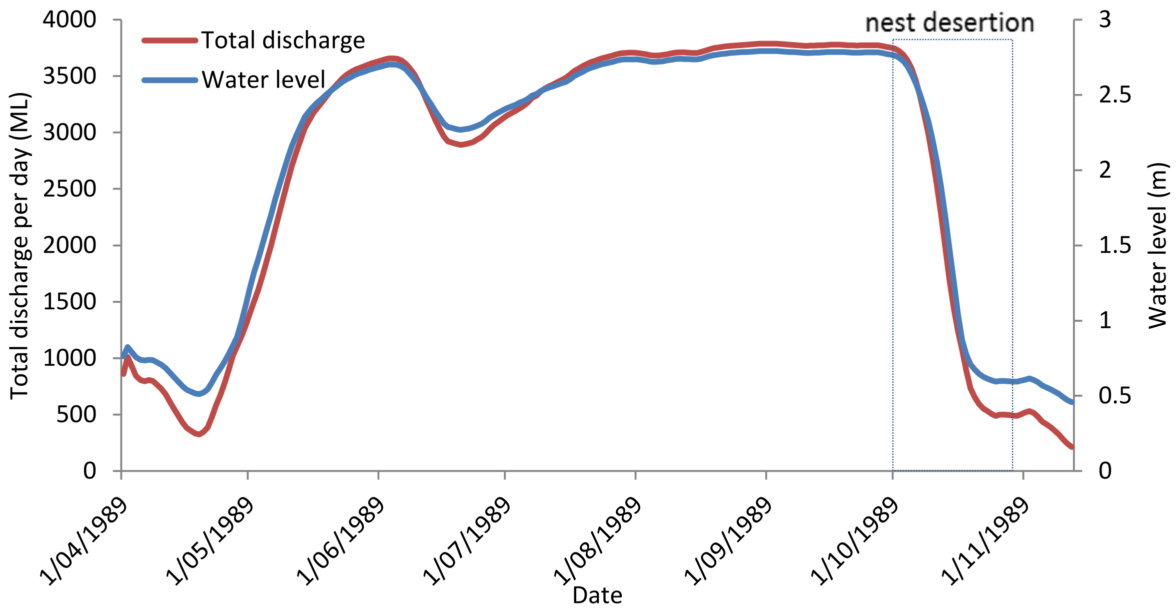


Figure 3 Daily flows and water levels at Booligal April. – Nov. 1989 with period of ibis breeding (dashed box) and nest desertion identified.

Historical flow data (1907-2015) were collated from WaterInfo NSW for the Booligal gauge (412005) (see Appendix 1). A simple analysis was undertaken to identify past opportunities for waterbird breeding. Following the work by Driver et al. (2005) who identified that to facilitate successful bird breeding, "a flow rate of 2,500 ML per day at Booligal gauge for a minimum of 50 days is recommended". The timing of these flows should be between June and November to reflect the natural flow patterns of the region." The data were analysed for periods where total daily flow exceeded 2,500 ML (Appendix 1).

Analyses of historical flows (1907-2015) at Booligal show there were 60 events where total daily flow exceeded 2,500 ML. Twenty-seven of these events had flow durations >50 days (Appendix 1). Only one (event no. 60) of these events occurred outside the optimal timing of June-November. The timing of flows that exceeded >2,500 ML per day were predominantly from July – September (48% of all flows), 20% occurred in October-December while the remainder (32%) occurred January – June.

In summary, these analyses found that there were 26 events between 1907-2015 that met the flow, duration and seasonal requirements, as identified by Driver et al. 2005, for successful waterbird breeding.

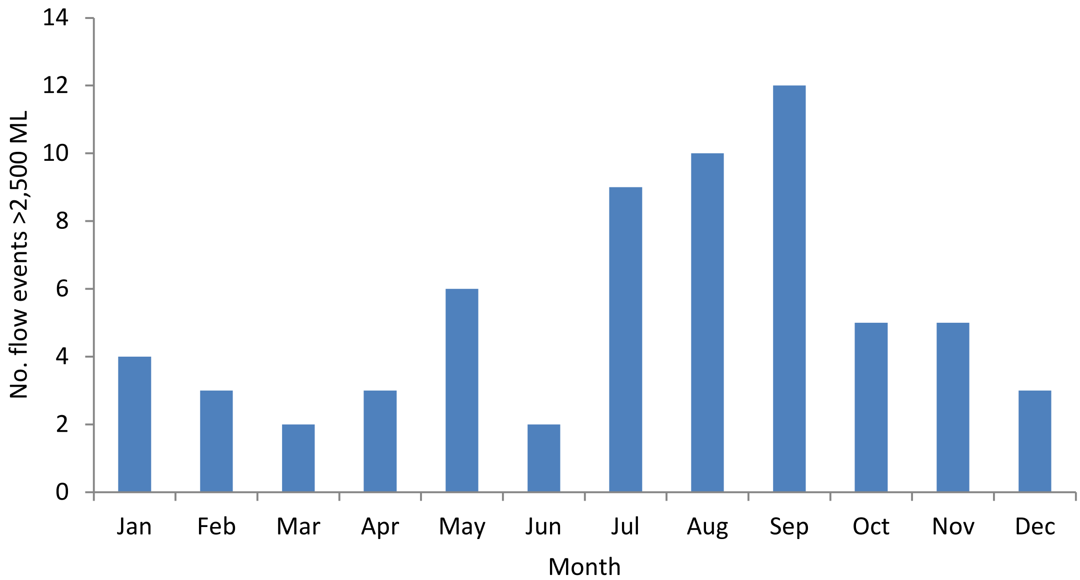


Figure 4 Seasonal analysis of months when flows >2,500 ML began.

Since 1984 when records of breeding have been regularly kept for Booligal Wetlands eight ibis breeding events have occurred on daily flows >2,500 ML at Booligal (Appendix 1; events 49, 51, 52, 54, 55, 56, 57, 58). Two events have occurred on daily flows volumes less than this, 2005 and 2010.

Six of the 8 breeding events occurred on floods with more than 50 days of flows exceeding 2,500 ML. Two breeding events (1996, 2000) occurred on floods with 18 and 28 days of >2,500 ML daily flows, respectively (Appendix 1). The breeding event in 1996 was relatively small with on 450 nests recorded (Table 1), and the 2000 breeding event was labelled a "miracle" event as it occurred on low managed flow volumes.

Current knowledge around flow thresholds required for ibis breeding at Booligal Wetlands are linked to flows at Booligal. This is, in part, due to a more complete flow record than available at other gauges. An alternative and possibly more appropriate gauge to be linked to ibis breeding for the purposes of flow management may be Merrimajeel @Block bank (412129) (Figure 4).

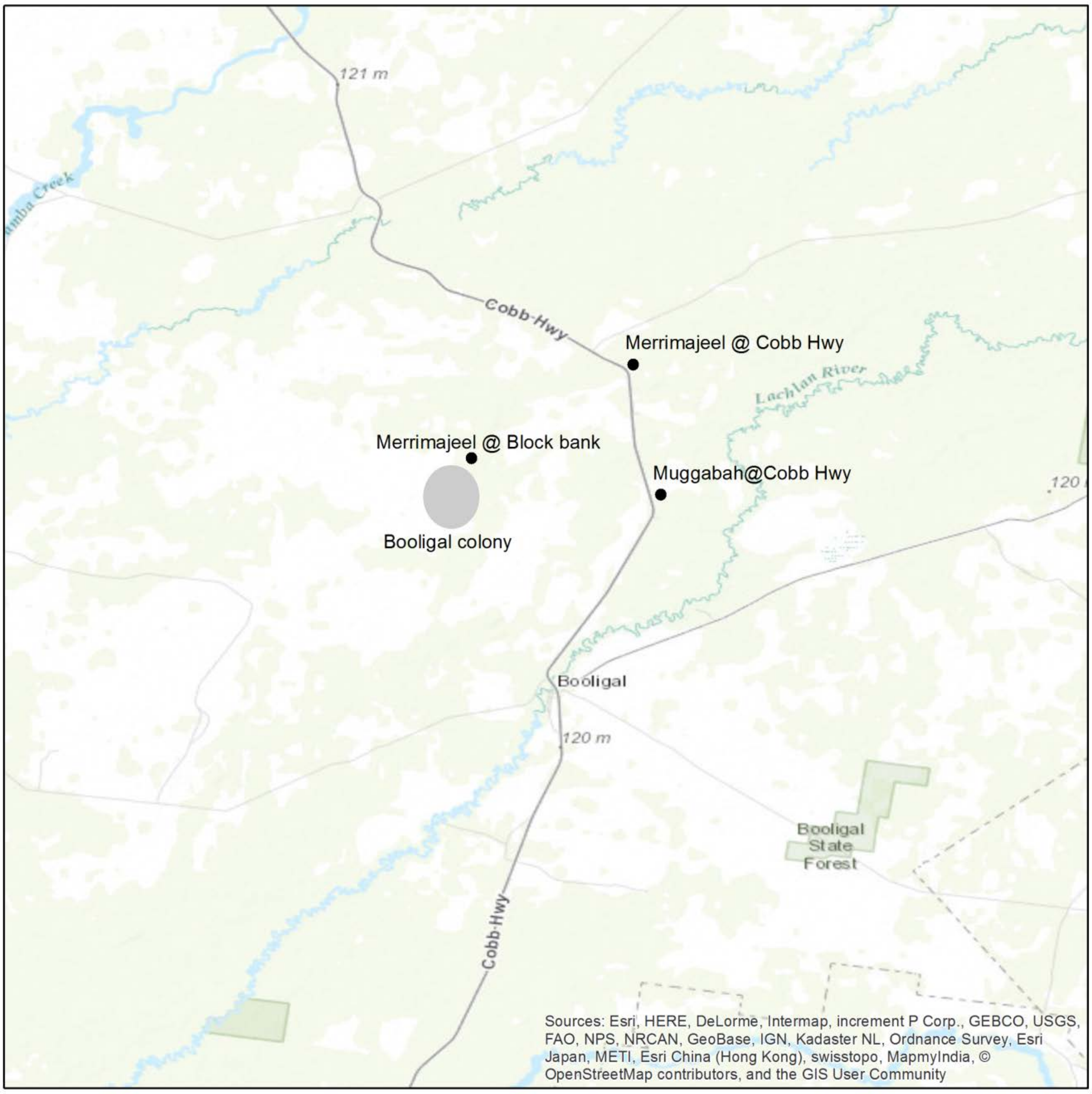
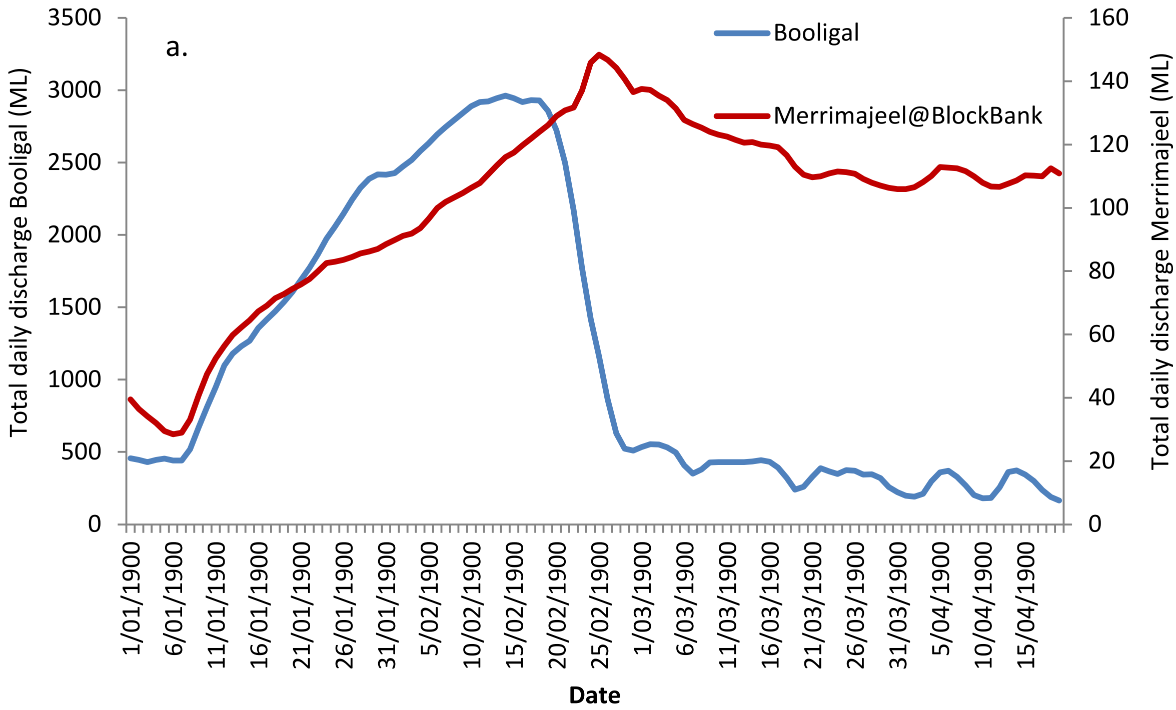
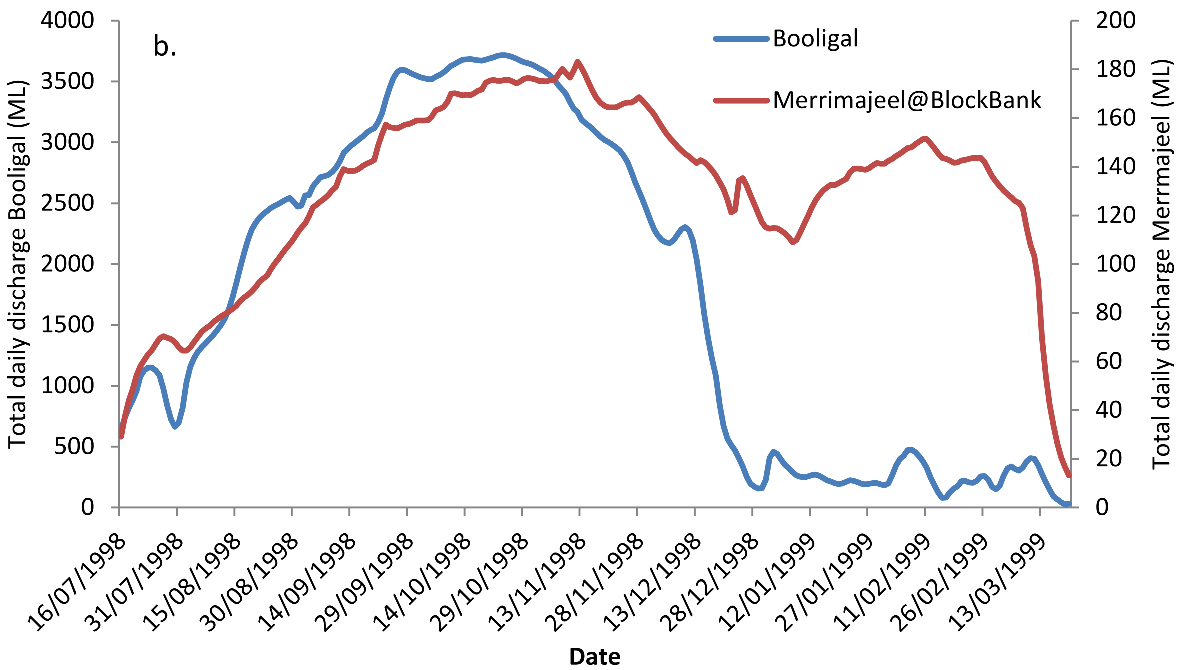


Figure 5 Location of flow gauges and the general colony area for Booligal Wetlands.

A review of available flow data for Merrimajeel@Block Bank gauge show that discharge data is limited with records of flow beginning in June 1994 and continuing (with significant gaps) until November 2012 (WaterInfo NSW accessed 3/6/16).

A preliminary analysis of the data was made to determine the flow volumes at Merrimajeel@Block Bank when flows at Booligal exceeded 2,500 ML (the breeding threshold). There were 5 occasions when this occurred.


a.
Booligal
Merrimajeel@BlockBank
Total daily discharge Booligal (ML)
Total daily discharge Merrimajeel (ML)
Date


b.
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Total daily discharge Booligal (ML)
Total daily discharge Merrmajeel (ML)
Date

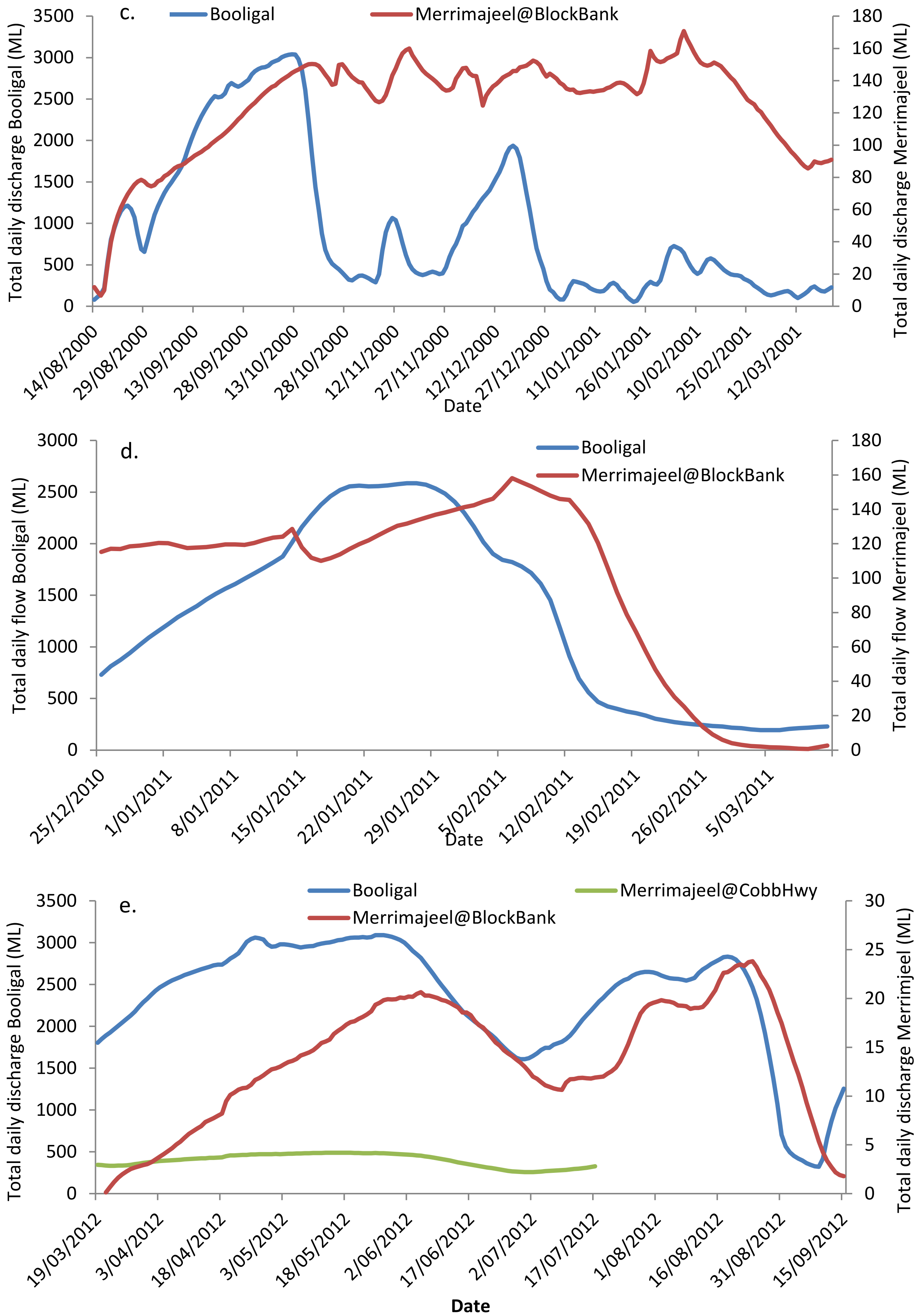


Figure 6 Flow at Booligal and Merrimajeel@Block Bank gauges during periods when flow >2500ML at Booligal a)1996, b)1999, c)2000, d)2010-2011, e) 2012.

Table 2 Flow volumes (max. and min.) recorded at Merrimajeel when corresponding flows at Booligal >2,500 ML.

Year	Reference Fig. 5	Maximum (ML)	Minimum (ML)
1996	a	148	91
1998	b	183	104
2000	c	150	102
2011	d	158	113
2012	e	23	4

The results of a very preliminary examination of the data suggest that flow volumes of ~>100 ML per day occur at Merrimajeel at times when flows exceed 2,500 ML at Booligal (Table 7). More comprehensive modelling and data analyses are required to more accurately determine the flow thresholds, and other hydrological conditions at Merrimajeel@Block bank that are associated with ibis breeding.

2005 ibis breeding event

In 2005 the Lachlan Catchment, in addition to many areas of the Murray Darling Basin, was experiencing the Millennium drought (1995-2012). Following the release of a replenishment flow to Merrowie Creek an ibis breeding colony established with between 5,000 – 10,000 pairs (Driver 2007). The breeding response of the ibis was unexpected as flows were relatively low and below that typically associated with ibis breeding. Additional water was provided to the colony site to maintain water levels and provide conditions suitable for successful completion of breeding.

The 2005 ibis breeding event in the Lachlan is similar to the 2008 ibis breeding event in the Narran Lakes Nature Reserve. Similarly, there had been an extended period of drought with very limited opportunities for breeding. Following upper catchment rainfall and filling of Clear and Back Lakes a large ibis breeding colony established (74,000 nests). Breeding was initiated on very low flows and the purchase of supplementary water was required to maintain water levels throughout the breeding period.

These two events may be examples of the impact of reduced breeding opportunities on decision making by ibis. The period of time between opportunities for breeding is critical in determining the number of reproductive opportunities a bird has in its lifetime and its contribution to the larger population. For example, straw-necked ibis have a life-span of 10-16 years (expert advice; comparison with other species of a similar body size), and sexual maturity is reached at 3-4 years (based on age at which adult plumage is achieved Marchant and Higgins 1999). Assuming that one chick per clutch reaches adulthood (Brandis et al. 2011, McKilligan 1975), a pair of ibis require at least two breeding opportunities in their lives to replace themselves and maintain population size.

Long inter breeding intervals have the potential to result in significant declines in waterbirds populations and reduced opportunities for breeding during the life span of an individual.

This will be critical if any waterbird species exhibit natal site fidelity. Whether any species do exhibit natal site is currently unknown but has been shown in other waterbird species (Hazllit and Butler 2001; Atwood and Massey 1988; Gratto 1988). If natal site fidelity is exhibited by some species then the frequency of breeding opportunities is critical.

Long or lengthening inter breeding periods may also result in ibis making decisions to breed during sub-optimal conditions e.g. low/small flow events. It needs to be recognised that while ibis bred on record low flows at both the Lachlan and Narran, that these flow volumes are not necessarily the threshold required for breeding. Both these events required additional flows to maintain conditions. These two events are anomalies and the result of a combination of extreme weather conditions (drought) and prior opportunities for breeding (very few).

Methods

This desktop review utilised a range of datasets including colonial waterbird breeding (EAWS 2015; Brandis 2010), climate data (Bureau of Meteorology), vegetation data (Bureau of Meteorology, Long Term Intervention Monitoring Program), hydrological data (NSW Office of Water, Commonwealth Environmental Water Holder) and bird behavioural observations (NSW Office of Environment and Heritage, Commonwealth Environmental Water Holder, EAWS 2015).

Colonial waterbird breeding

Since the 1980s, ten major waterbird breeding events have been recorded, including a large ibis breeding event in 2010 (EAWS 2015). Environmental water has been used at this site since 1984 to assist in the successful completion of waterbird breeding. The 'block bank', located at Booligal Wetlands, has been used in all waterbird breeding events since 1984, in conjunction with environmental water diversions from Torriganny Weir (MDBA 2012). It was also used during flows in 2015 to stabilise water levels at the colony site (Appendix 2).

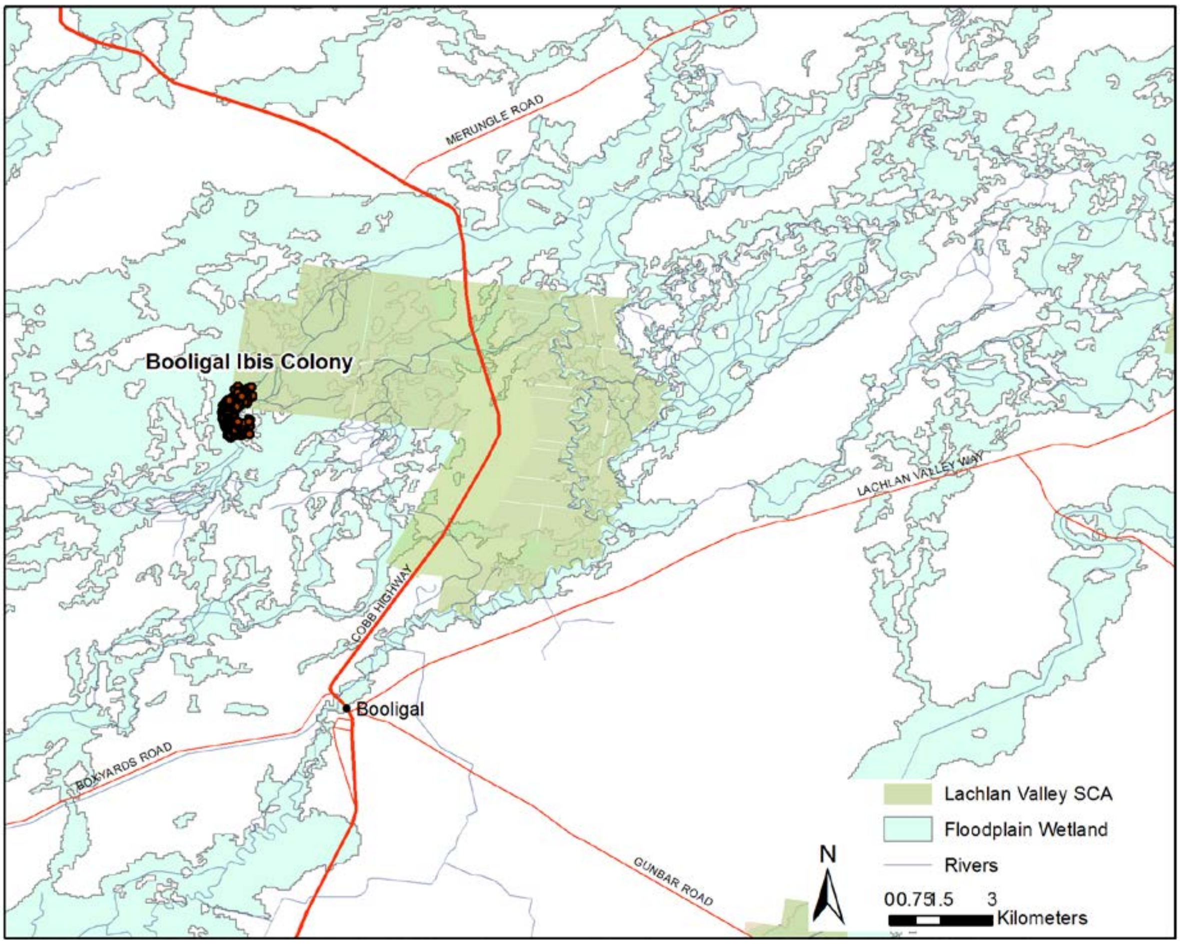


Figure 7 Location of active nests during the 2010-11 breeding event when straw-necked ibis nested in Booligal Wetlands on the edge of the Lachlan Valley State Conservation Area. (source: NSW OEH, Appendix 2).

Climate data

Rainfall and temperature data were collated from the Bureau of Meteorology for August-December 2015 and the long-term averages (http://www.bom.gov.au/climate/averages/tables/cw_075032.shtml).

Vegetation data

Monthly Normalised Difference Vegetation Index (NDVI) data were collated from the Bureau of Meteorology for August-December 2015 (http://www.bom.gov.au/climate/austmaps/about-ndvi-maps.shtml).

The Normalised Difference Vegetation Index (NDVI) grids and maps are derived from satellite data. The data provides an overview of the status and dynamics of vegetation across New South Wales, providing a measure the amount of live green vegetation (BOM 2016). NDVI provides a measure of vegetation density, condition, and the fractional cover of the ground vegetation (BOM 2016). The vegetation density and greenness is indicative of the photosynthetic capacity of the land surface cover (BOM 2016).

NDVI is calculated from the red and near-infrared reflectance (BOM 2016) and expressed as values between -1 and +1. Vegetation NDVI in Australia typically ranges from 0.1 up to 0.7, with higher values associated with greater density and greenness of the plant canopy. NDVI decreases as leaves come under water stress, become diseased or die. Bare soil and snow values are close to zero, while water bodies have negative values (BOM 2016).

Monthly NDVI is a composite of the NDVI values from cloud-free observations in the month from the operational afternoon NOAA satellite. There are, in the absence of cloud, usually one and sometimes two observations per day.

On ground vegetation condition was recorded by the survey team undertaking the Long Term Intervention Monitoring.

Hydrological data

Hydrological data was collated from NSW WaterInfo (http://waterinfo.nsw.gov.au/) and the Commonwealth Environmental Water Office.

Bird behaviour

Observational data (field) has been collected from NSW Office for Environment and Heritage Commonwealth Environmental Water Office, and the Centre for Ecosystem Science, UNSW. For the period August – November 2015.

Statistical analyses

To build on previous waterbird response modelling by Driver et al. (2005) and include more recent ibis breeding events we tested for associations between environmental metrics and annual ibis breeding events. Generalized linear models were used with a binomial response using flow and breeding data for the period 1984-2015. Environmental metrics thought to be important to waterbird breeding were identified representing flow volumes (Booligal), air temperature (Hillston Airport) and rainfall (Booligal, Belmont).

Results

Climate data

Rainfall

Hillston Airport recorded a higher than average (369.8 mm) rainfall year (2015) with 447.5 mm. November 2015 had very high rainfall placing it above the 90th percentile for the long-term average (1881-2016) (Table 3). Booligal (326.2 mm) and Balranald (288.6 mm) (Figure 4) recorded near or below the annual long-term averages of 331.7 mm and 323.5 mm respectively. The upper catchment of the Lachlan River was the wettest area of the Murray-Darling Basin during July – September 2015 (Figure 3).

Table 3 Rainfall records for Hillston Airport for the period of interest August-December 2015.

Month	Long term average* mm	2015 rainfall mm
August	30.9	**36.2**
September	27.6	16.2
October	35.6	26.0
November	29.1	**67.4^**
December	30.1	**38.2**

*Average of all years of data 1881-2015.

^above 90th percentile

Table 4 Rainfall records for Booligal for the period of interest August-December 2015.

Month	Long term average* mm	2015 rainfall mm
August	27.2	**36.6**
September	25.4	**16.3**
October	31.8	**4.8**
November	25.2	**26.0**
December	25.0	**34.2**

*Average of all years of data 1890-2015.

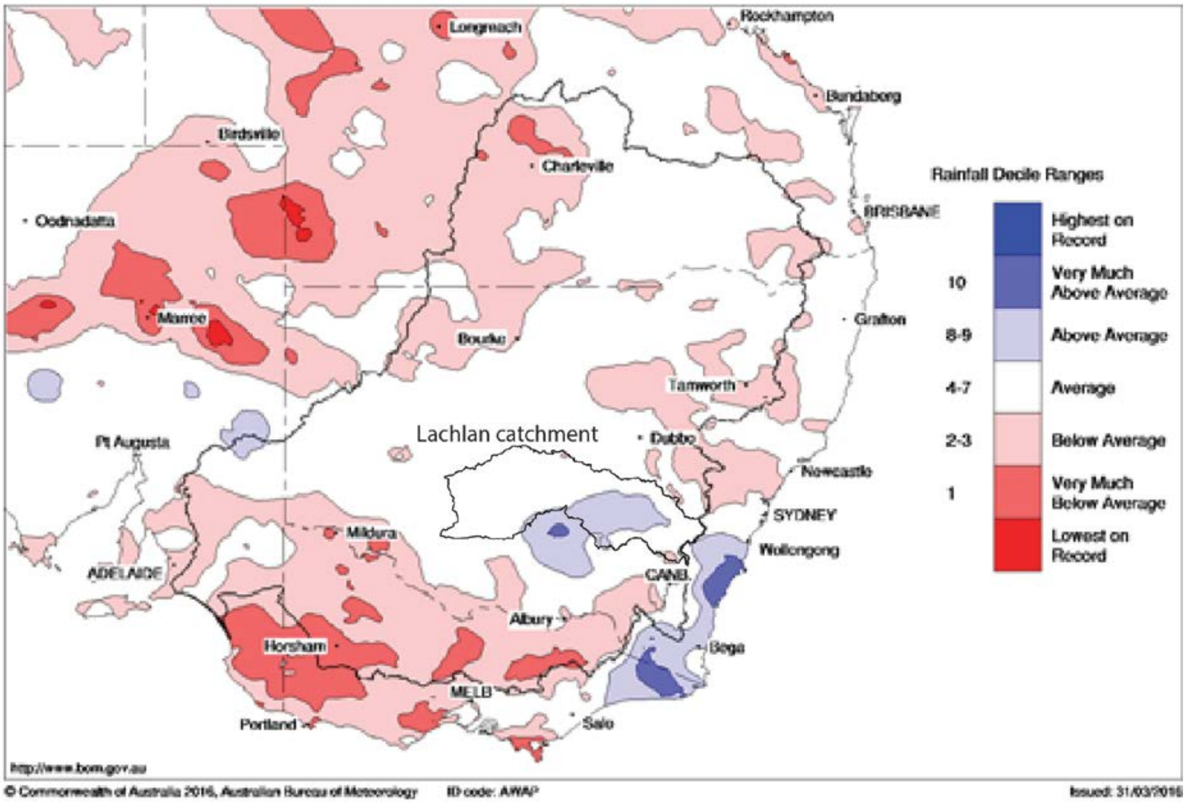


Figure 8 Murray-Darling Basin rainfall deciles 1 July – 30 September 2015, showing the upper Lachlan catchment being the wettest region of the Basin during this period (source: Australian Bureau of Meteorology).

Temperature

Rainfall was discussed from a long term perspective, and therefore long term temperature anomalies need consideration. October, November and December 2015 experienced higher than average temperatures, both maximums and minimums across the region (Figure 9).

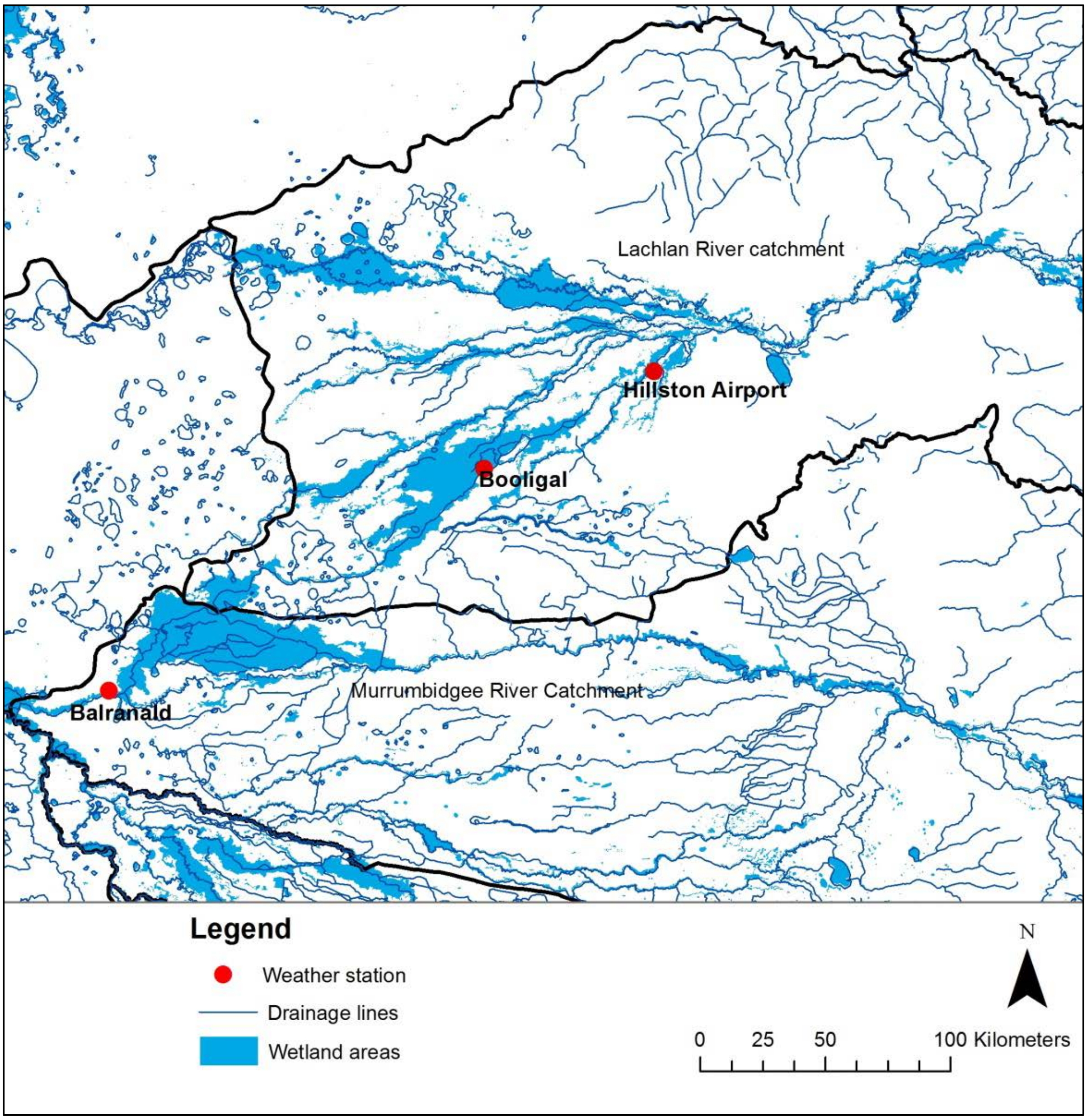


Figure 9 Location of weather stations with regards to placement in catchment and wetlands.

Table 5 Temperature data (^{0}C) for Hillston Airport August-December

Month	**Long term mean maximum***	**2015 max.**	**Long term mean minimum***	**2015 min.**
August	17.1	16.2	4.9	5.3
September	20.8	20.5	7.1	5.3
October	24.8	**30.6**	10.3	**13.1**
November	28.6	**30.5**	13.7	**14.9**
December	31.6	**33.5**	16.4	**17.6**

*Long term data derived from all years of data 1881-2015.

Table 6 Temperature data (^{0}C) for Balranald August-December

Month	Long term mean maximum*	2015 max.	Long term mean minimum*	2015 min.
August	17.6	16.4	4.7	5.7
September	20.9	20.5	7.1	5.4
October	24.6	**35.0**	9.8	No data
November	28.1	**29.7**	12.6	**14.1**
December	30.9	**34.5**	14.8	**17.8**

*Long term data derived from all years of data 1879-2015.

No temperature data available for Booligal.

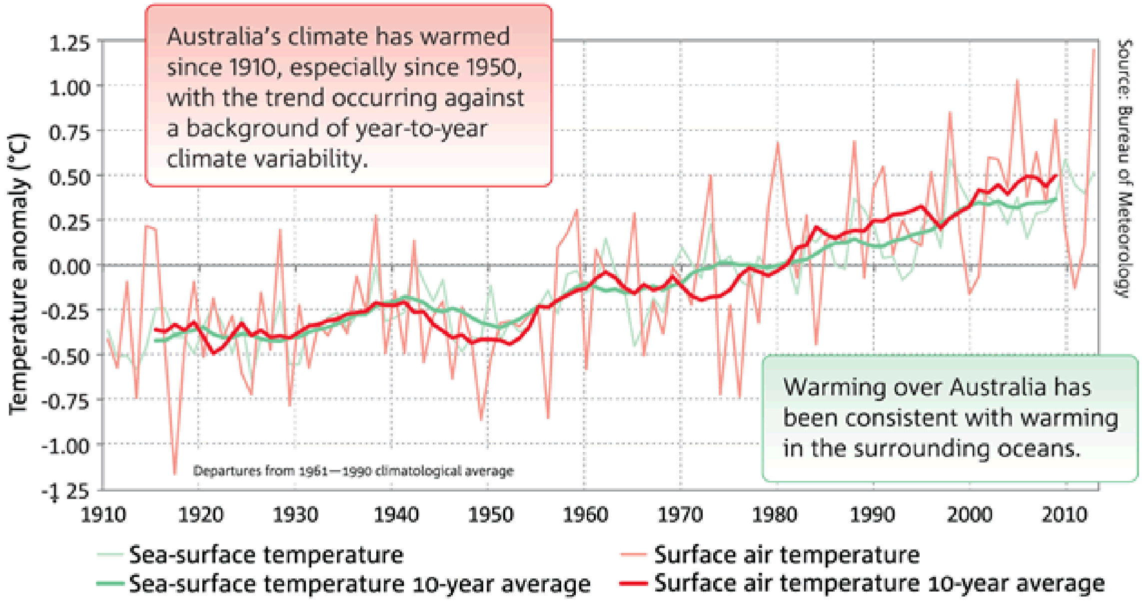


Figure 10 Long-term trends in sea-surface temperatures and surface air temperatures illustrating the warming of Australia's climate 1910-2010 (source Bureau of Meteorology).

Since 2001, the number of extreme heat records in Australia has outnumbered extreme cool records by almost 3 to 1 for daytime maximum temperatures, and almost 5 to 1 for night-time minimum temperatures (http://www.bom.gov.au/state-of-the-climate/).

Vegetation

Normalised Difference Vegetation Index (NDVI)

There was a substantial contraction of 'greenness' towards the NSW coast between September (Figure 11) October (Figure 12) and November 2015 (Figure 13). This coincides with the above average temperatures experienced in the region during October, November and December (Table 5, Table 6) and the seasonal change expected from Spring to Summer.

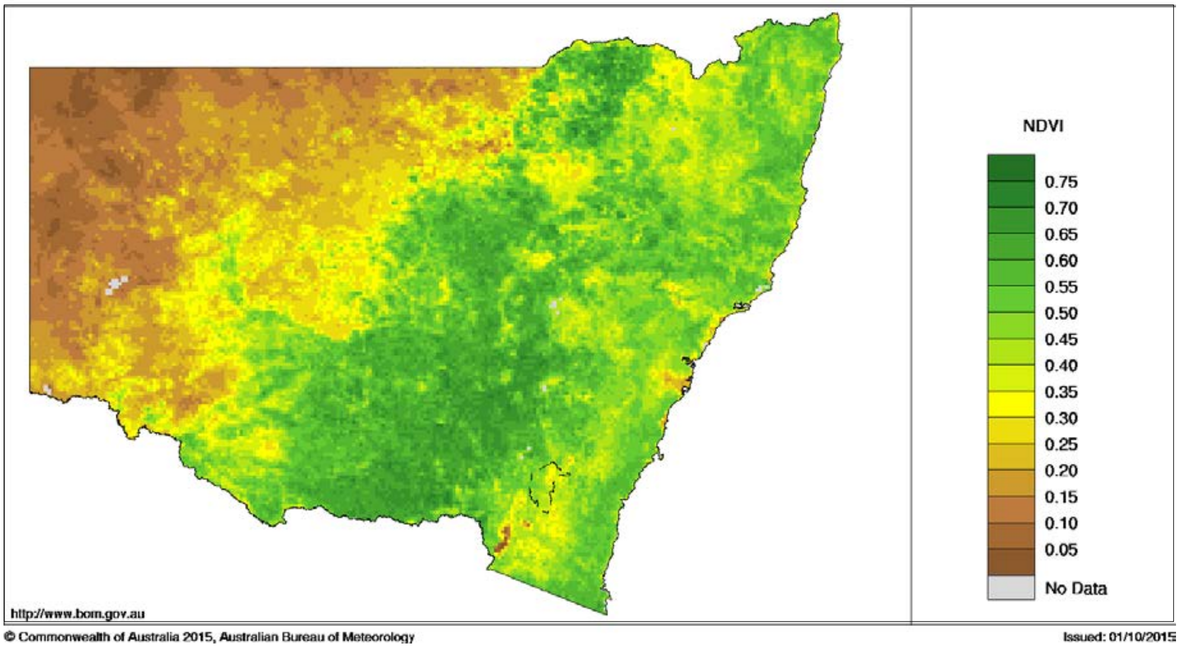


Figure 11 Normalised difference vegetation index (NDVI) September 2015. Source: Australian Bureau of Meteorology.

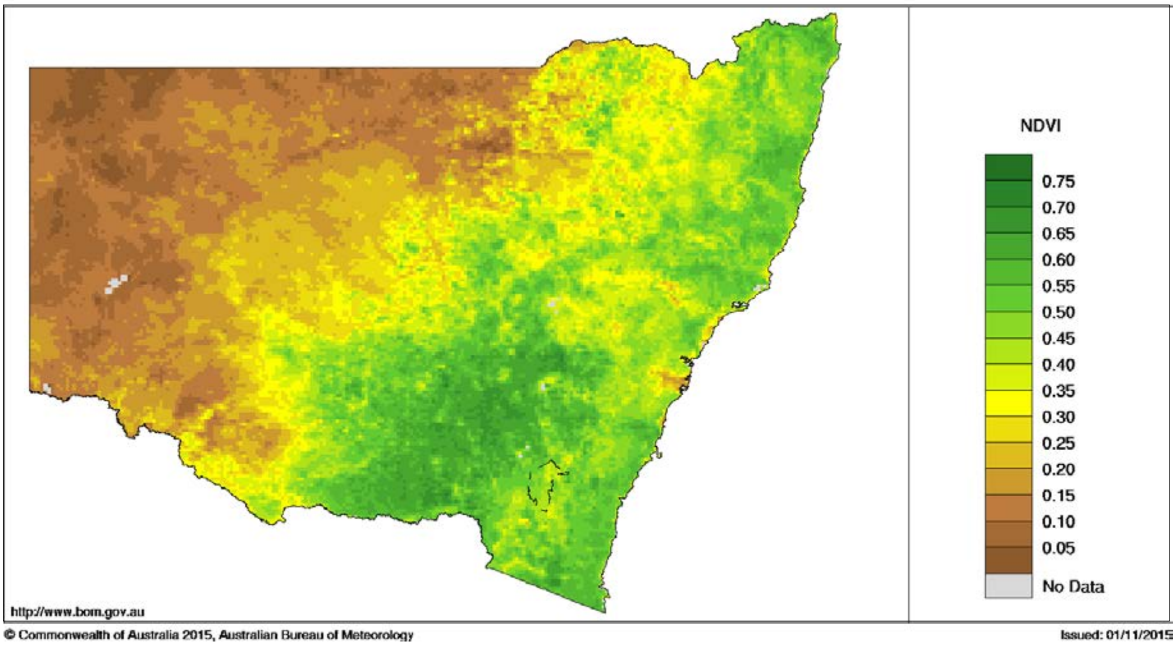


Figure 12 Normalised difference vegetation index (NDVI) October 2015. Source: Australian Bureau of Meteorology.

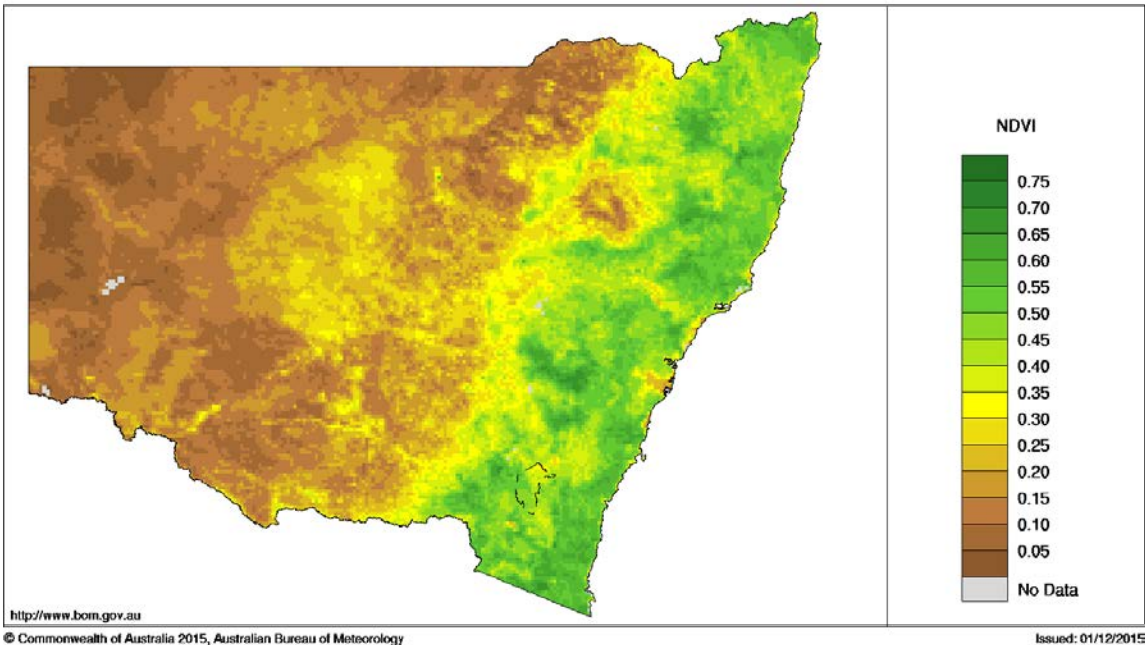


Figure 13 Normalised difference vegetation index (NDVI) November 2015. Source: Australian Bureau of Meteorology.

Vegetation Long Term Intervention Monitoring Survey

Vegetation surveys in the Lachlan catchment were undertaken as part of the Long Term Intervention Monitoring program. Observations made by Dr Fiona Dyer, leader of the vegetation monitoring program match those seen in the NDVI images and illustrate the widespread conditions in the catchment and region (Appendix 3). In May 2015 the catchment was dry. By September following heavy rainfall and translucent flows from the dams the vegetation responded and the catchment was very green. In October/November the catchment had dried again with areas of drying or dead vegetation.

Hydrology

In response to above average rainfall across the Lachlan catchment in winter 2015, inflows to Wyangala Dam exceeded thresholds for planned environmental water (translucent releases) (Figure 14) provided under the Lachlan Regulated River Water Sharing Plan in September 2015 (see WSP 2003). In addition, the Commonwealth Environmental Water Holder (CEWH) and NSW Office of Environment and Heritage (NSW OEH) provided environmental flows prior, and subsequent to the translucent event, to provide a slower flow recession. A component of this translucent flow reached Booligal on the 9th August (Figure 15), and flows down Merrimajeel Creek inundated the Booligal Wetlands by early September (Figure 16).

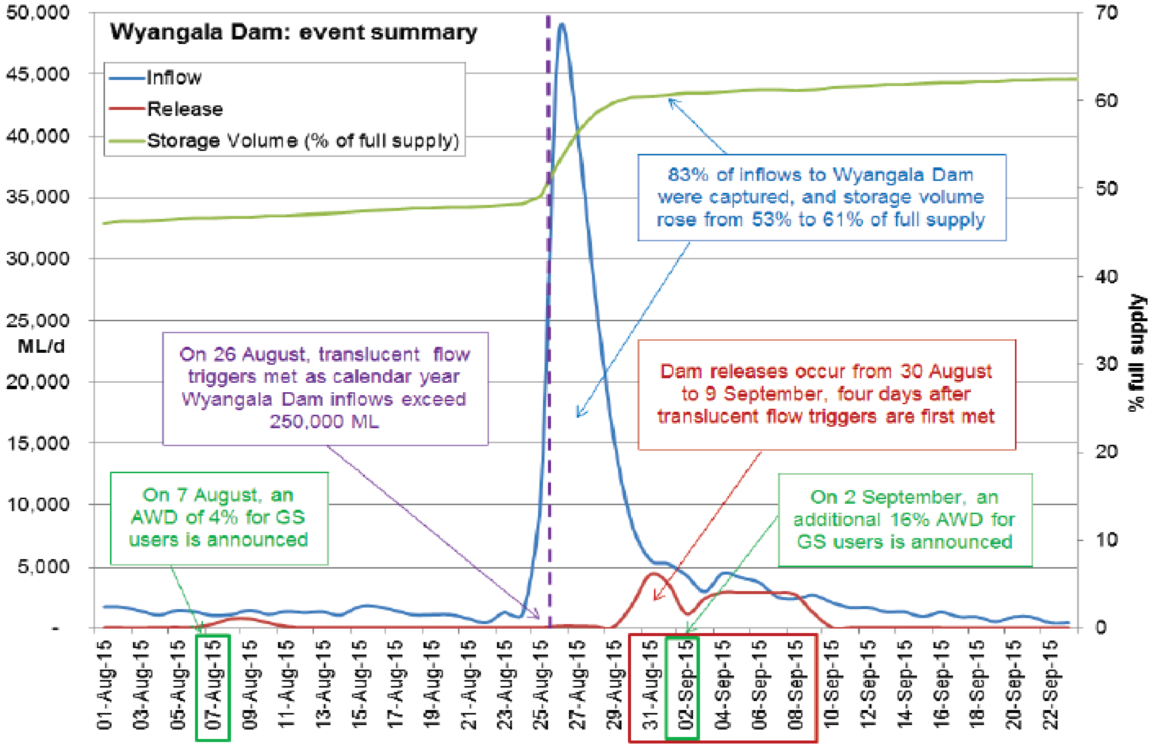


Figure 14 Details of flow releases from Wyangala Dam (August-September 2015) (source: http://www.water.nsw.gov.au/__data/assets/pdf_file/0003/586434/a-translucent-dam-release-event-lachlan-august-2015.pdf)

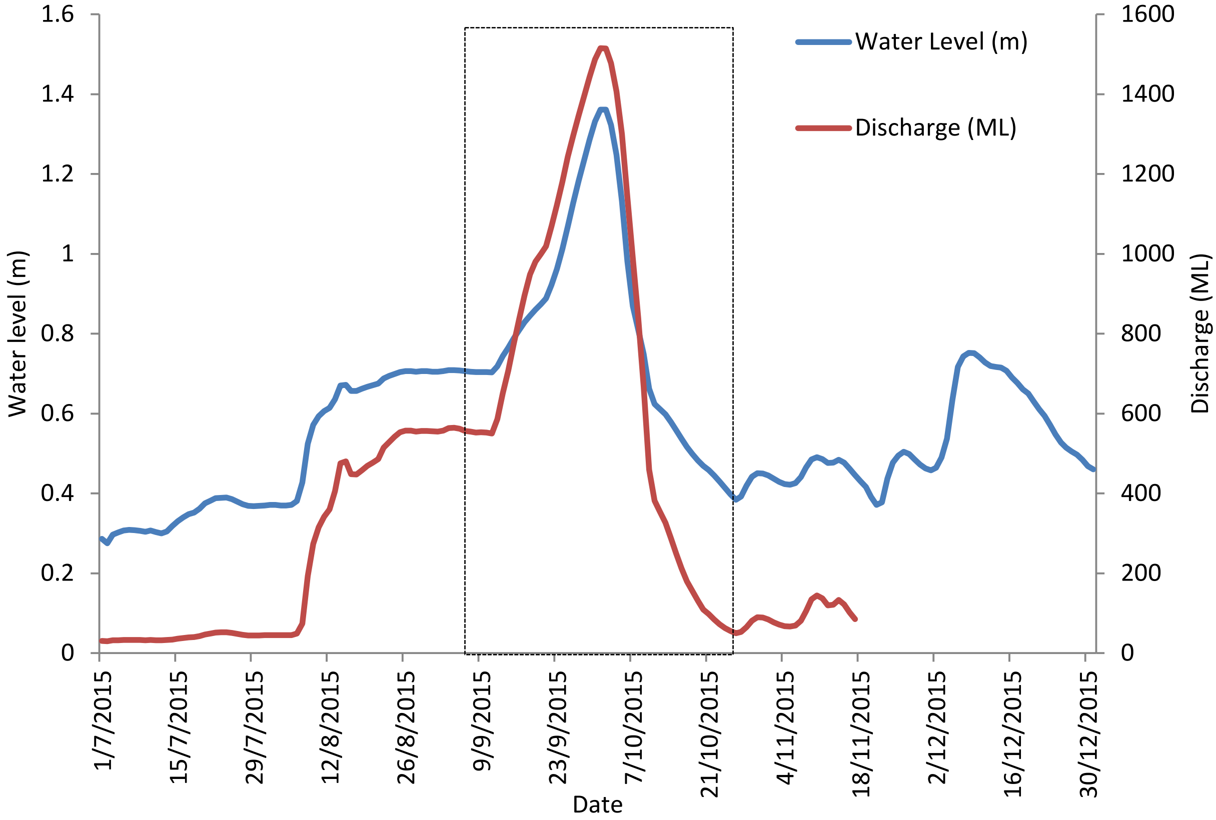


Figure 15 Total daily flows and river height at Booligal (412005) July – December 2015 with box identifying the period during which straw-necked ibis were observed.

Coinciding with the peak of the hydrograph in September-October 2015 were the observations of straw-necked ibis in the Booligal Wetlands (Figure 15).

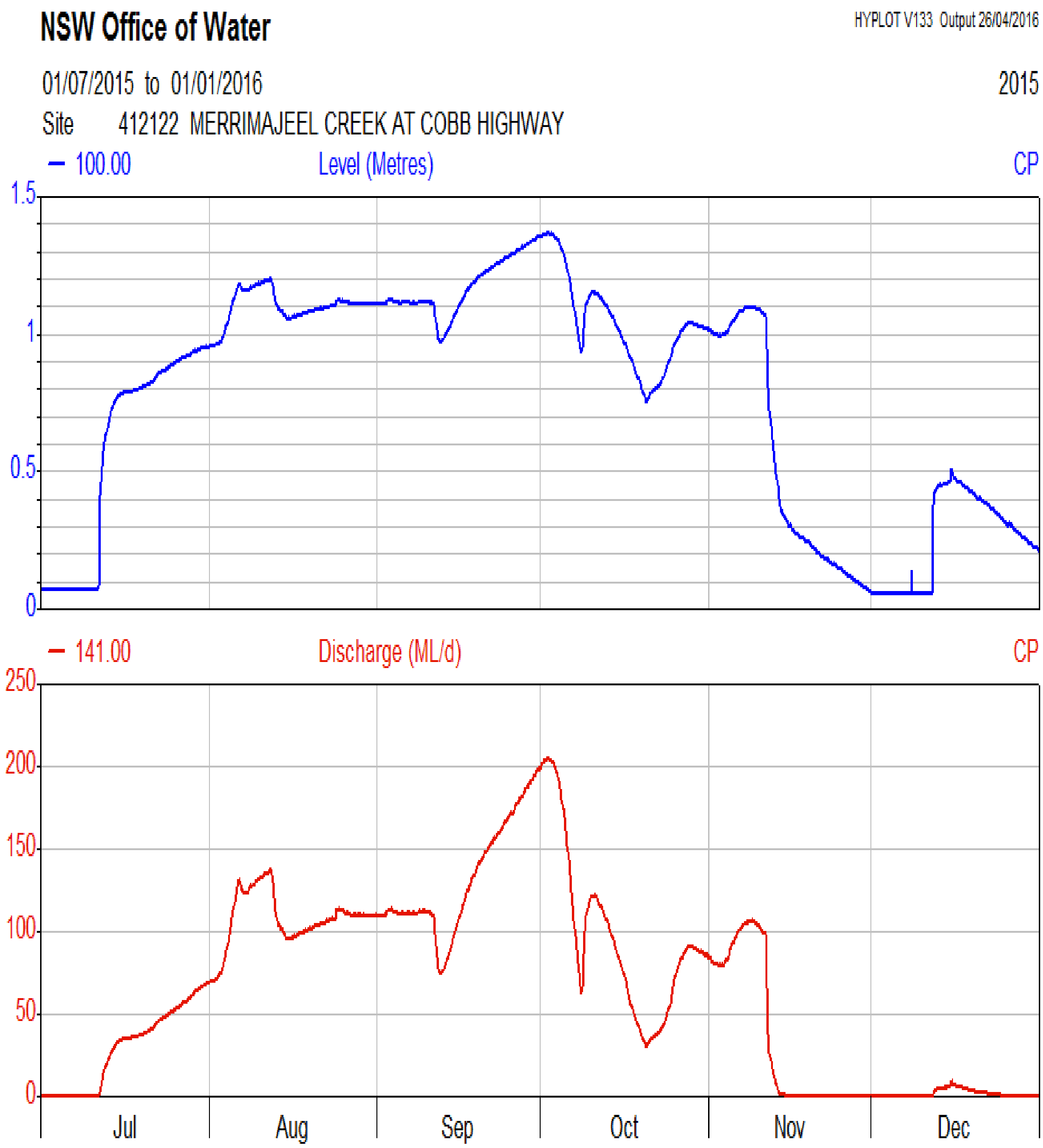


Figure 16 Water level (m) and discharge (ML) at Merrimajeel Creek July – December 2015. (Data provided by NSW Environment and Heritage).

Flows in Merrimajeel Creek rose and receded over a short time period (with water levels increasing from 0 – 80cm within days in July 2015 (Figure 16). Water levels then fluctuated between 75cm and 1.35cm before dropping rapidly in November 2015 (Figure 16).

Bird behaviour

The Booligal Wetlands were inundated by the 10th September (Figure 17) and large numbers of straw-necked ibis were observed congregating in the lower Lachlan. In mid-October ibis were observed at the traditional colony site near the Block bank, however by late October the straw necked ibis had left. There was evidence of trampling of lignum, the first stage of nest building, however no nests were observed.

The breeding behaviour, including nesting, of ibis is closely tied to inundation and water depths (Brandis et al. 2011). Insufficient flooding or rapid decreases in water depth can result in either failure to initiate breeding or loss of chicks during nesting (Brandis and Bino 2016; Brandis et al. 2011) (Figure 17).

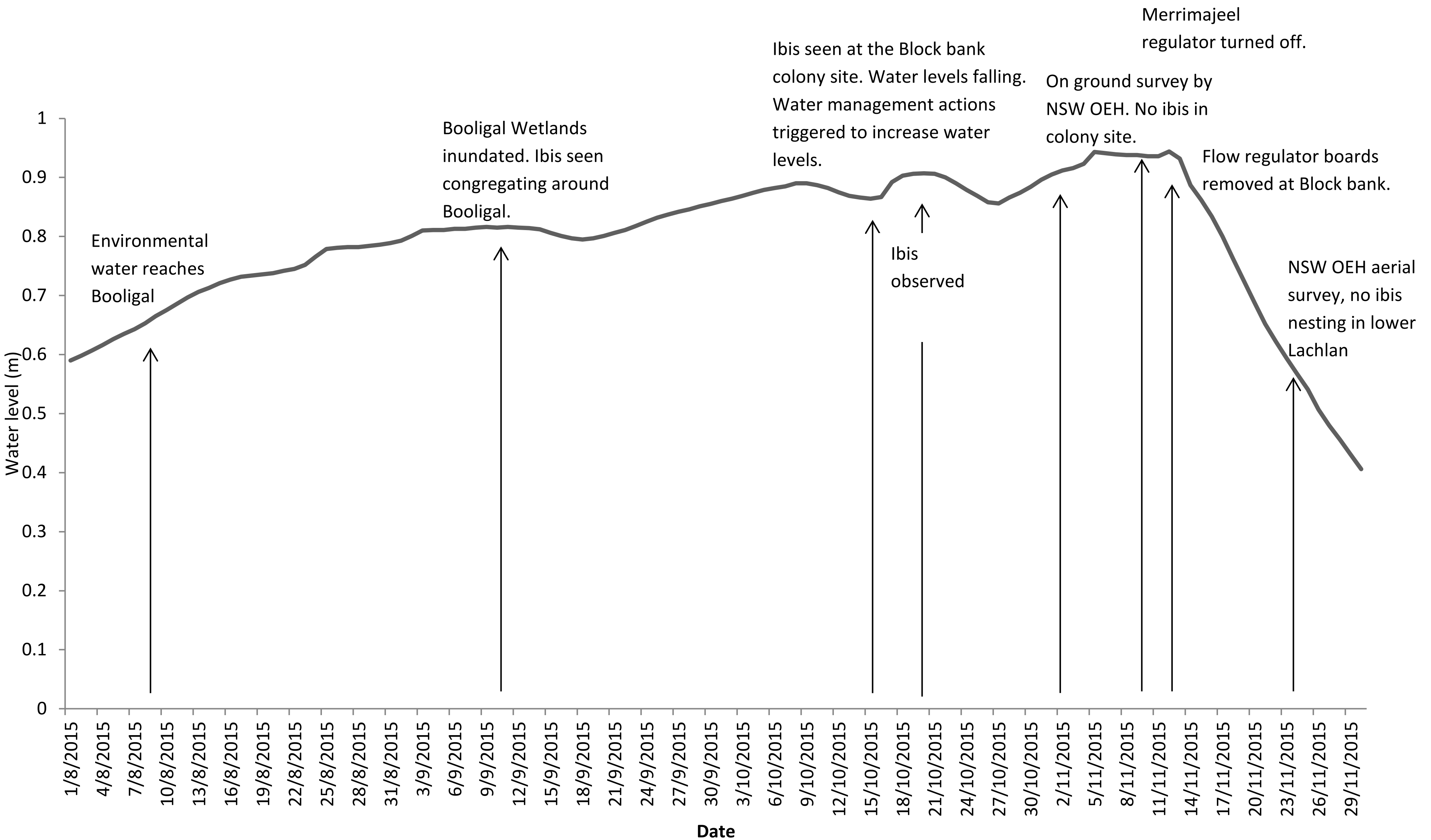


Figure 17 Timeline of events showing water levels at Merrimajeel Block bank and observed ibis behaviour.

Statistical analyses

G, Bino and K, Brandis

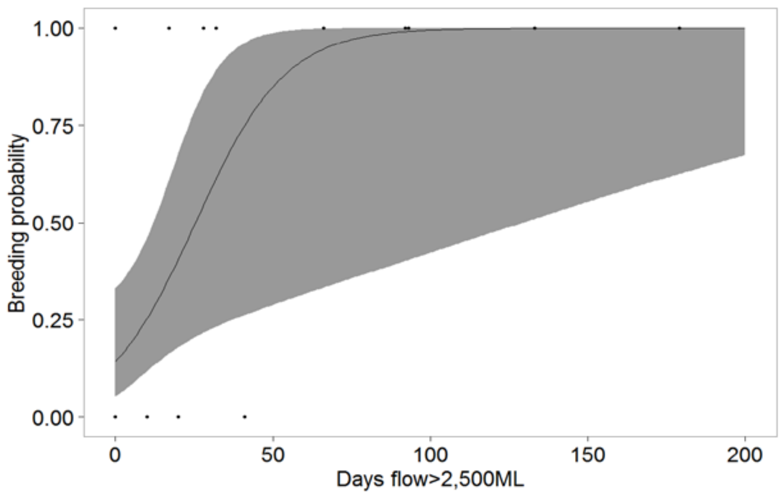
Associations between environmental metrics and annual ibis breeding events (1984-2015) were examined using generalized linear models with a binomial response. Ten plausible environmental metrics were identified representing flow volumes (Booligal gauge), air temperature (Hillston Airport) and rainfall (Booligal, Belmont), (Table 7). In line with optimal breeding timing, explanatory metrics were derived between June and November. Models were developed for each of the ten explanatory metrics (predictors) separately as well as possible combinations of explanatory metrics. Given the small sample size of 33 years, of which 11 had a breeding event, model complexity was restricted to three explanatory metrics. Explanatory metrics were standardized (z-score) to allow comparison of effect size. Model performance was assessed using the corrected Akaike Information Criterion (AIC) goodness of fit metric. Seven of the ten explanatory metrics were within 2 AIC scores of the best fit single predictor model. Total number of daily flows greater than 2,500ML had the largest effect size and provided the best fit model with breeding events (Table 8). Total flow volumes and total number of daily flows greater than 2,000ML followed in model fit and effect size (Table 8). Average air temperature at Hillston Airport was found to have a negative association with probability of breeding events. Average and total rainfall were also found to have a positive association with probability of breeding. Of models with two explanatory metrics, total number of daily flows greater than 2,500ML and either average or total rainfall at Booligal (Belmont) provided the best fit models. These were followed by total number of daily flows greater than 2,000ML and either average or total rainfall at Booligal (Belmont), and total flow volumes and either average or total rainfall at Booligal (Belmont). Lastly, water level and rainfall (average and total) were also considered as plausible models. Eighteen models with three explanatory metrics were identified within 2 AIC scores of the best fit model. Of those, ten incorporated total number of daily flows greater than 2,500ML, nine total and average rainfall and six incorporated average temperature, number of daily flows greater than 2,000ML and 1,500ML. Maximum air temperature (four models), total flow volume (2 models), and average water level (2 models) were also considered.

Statistical analyses also found that the probability of breeding occurring were maximised when there was ~100 days of flows >2,500 ML (Fig. 18a), or when total flow volumes were 500 GL (Fig. 18b). The probability of breeding decreased with increasing air temperature (Fig. 18c). However the probability of breeding increased with increasing average daily rainfall to 2mm/day where it was maximised (Fig. 18d).

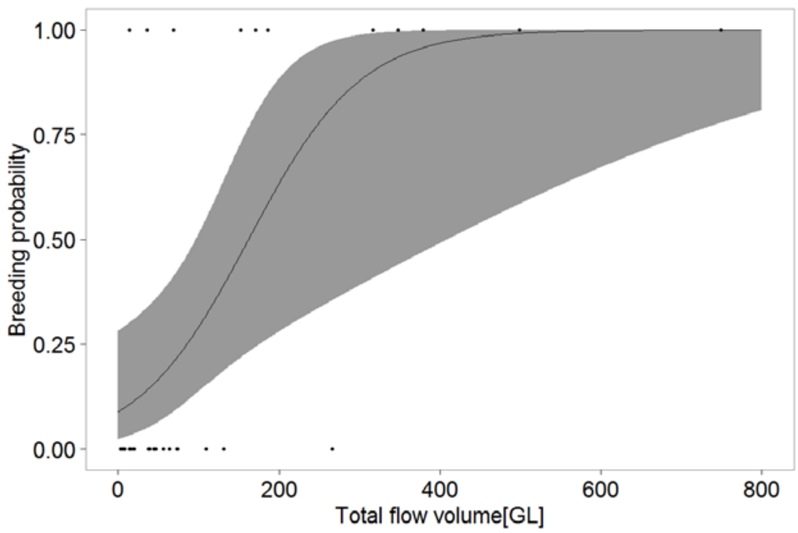
Table 7 The 10 explanatory variables assessed with regards to ibis breeding (1984-2015) and goodness of fit metrics (AIC) using a generalized linear model with a binomial response.

Independent variable	ΔAIC	R^2	Coefficient
Total annual flow volume	0.47	0.37	2.42
Average daily flow level	2.12	0.34	1.98
Total number of daily flows above 2,500ML	0.00	0.38	3.05
Total number of daily flows above 2,000ML	0.77	0.36	2.31
Total number of daily flows above 1,500ML	2.98	0.32	1.74
Average air temperature	1.15	0.36	-2.06
Maximum air temperature	12.07	0.1	-0.75
Minimum air temperature	8.00	0.1	-1.23
Total annual rainfall	1.88	0.34	2.00
Average daily rainfall	1.88	0.34	2.00

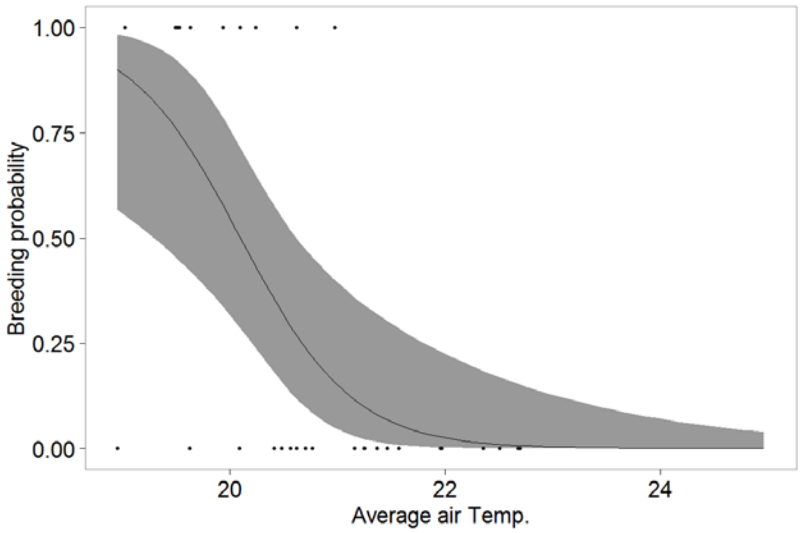
A.



B.



C.



D.

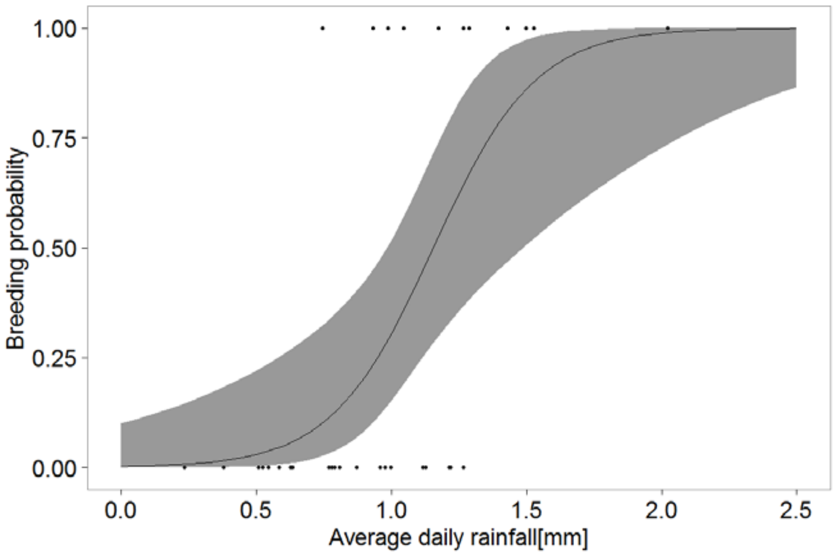


Figure 18 Predicted breeding probability for A) total daily flows greater than 2,500ML , B) total flow volumes [GL], C) average daily air temperature at Hillston Airport, and D) average daily rainfall based on the generalised linear model. Historic breeding records are depicted as black points.

Discussion 2015

Ibis were observed in the lower reaches of the Lachlan catchment (Figure 16) for about 6 weeks from 10th September to mid-late October (NSW OEH pers comm., Eastern Australia Aerial Survey 2015). There are several factors that may have contributed to the observed behaviour of ibis at this time. These include:

Climate
There were hotter than average temperatures for the region (Table 5; Table 6), and very low rainfall in October at Booligal (Table 4). This is reflected in the NDVI with a substantial decrease in greenness from October-November, and observations made by the LTIM survey team (see Appendix 3). It is possible that these conditions had an impact on availability of food resources (Jenkins and Boulton 2007; Jenkins et al. 2009).

Hydrology
Rapid declines in both flows and water levels measured at Booligal (Figure 15) during the period over which ibis were observed in the colony area.

Previous work by Driver et al. 2003 found that between 1984-2000 breeding at Booligal occurred when flows were greater than 2,500 ML/day at Booligal Weir. Maximum flows during the 2015 environmental flows were a maximum of 1,515 ML (1/10/15).

During this time flows in the main channel at Booligal fell rapidly over a period of about 7 days (Figure 15) while water levels were more stable at the traditional colony site there was an overall increase in depth of ~10cm from the lowest level at 79.5cm (18th Sept.) to the peak height 90.7 cm (20th October) over a 33 day period (Figure 12).

Environmental cues
There is very little known about the environmental cues that birds use to make decisions. This is particularly true of waterbirds and decisions surrounding breeding (McKilligan, 1975). Our understanding of waterbird breeding ecology is that they have requirements that include:

a) Hydrological conditions
b) Food resources
c) Suitable habitat

Current management tools for supporting waterbird breeding events are focused on the provision of suitable hydrological conditions both for breeding and for the maintenance of nesting vegetation. Hydrological management tools can be applied to water depth, duration of inundation, flow volumes and seasonal timing (Brandis and Bino 2016, Merritt et al. 2016). This was demonstrated during the 2015 flows to Booligal when the Block bank regulator was used to stabilise water levels at the traditional colony site (Appendix 1).

However we assume that food resources must also play a critical role in influencing decision making by waterbirds. The availability of food resources during the nest preparation stage will be important for the build-up of body condition required for breeding. There are well recognised stages of breeding that determine duration of breeding: build-up of body condition (Briggs et al. 1991), courtship, nesting and egg laying, incubation, chick provisioning, fledging and post fledging. Once breeding is initiated, there needs to be sufficient ongoing resources to allow for successful completion of breeding (Brandis and Bino 2016). Trampling and preparation for nesting and egg laying are the first stages of breeding by straw-necked ibis. If food resources were not suitable for the rapid build-up of body condition required for egg laying then the progression to the next stage of breeding may not occur.

Regional conditions

Waterbirds are often identified as indicators of wetland health. This is due to their top order consumer position in the food web, their mobility and ability to choose wetlands habitats that best meet their requirements (food, nesting, roosting). For many species a single wetland is only one of many habitat patches in a much larger mosaic. As a result the management of wetlands need to be considered at a larger scale than the individual. For the case of terrestrial feeding waterbirds, such as ibis, it also needs to include the surrounding landscape as a source of food resources. The 2015 Straw-necked ibis response in the lower Lachlan potentially demonstrates this. Ibis initially responded to the 'good' conditions. The catchment and region had received widespread and above average rainfall (Table 3,Table 4), vegetation conditions were healthy and responsive (Appendix 3) suggesting that other food web mechanisms were also functioning, i.e. insect emergence. There were in channel river flows and inundation of the Booligal wetlands. Conditions across the catchment then altered with higher than average temperatures (Table 5,Table 6) and a rapid drying off of vegetation (Figures 11- 13). At the same time flows in the main channel dropped rapidly (Figure 15). The combination of drying vegetation, impacting on the availability of food resources and falling water levels in the main channel may have provided the cues necessary for ibis to cease nesting behaviour and find alternative habitats.

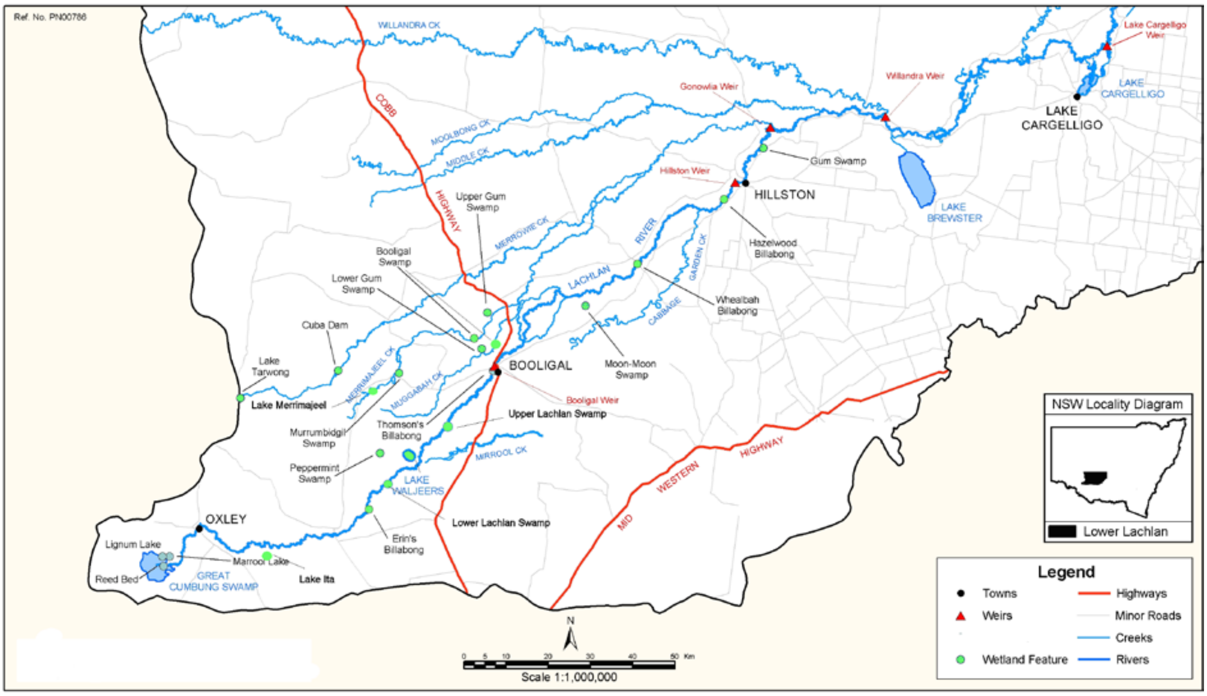


Figure 19 Lower Lachlan wetlands (source: Barma Water Resources et al. 2011)

The Booligal Wetlands are one in a large mosaic of wetlands both within the Lachlan catchment (Figure 19) and the region (Figure 20). Due to the mobility of waterbirds they can easily choose to change habitats, particularly if there is a large choice within the region. During September – November there were inundated wetland habitats also available in the Lowbidgee Wetlands and the Barmah-Millewa Wetlands where Australian white ibis and straw-necked ibis bred in small numbers. Waterbirds were also seen feeding in large numbers at the Great Cumbung swamp (confluence of Lachlan and Murrumbidgee Rivers) in late November (Figure 19).

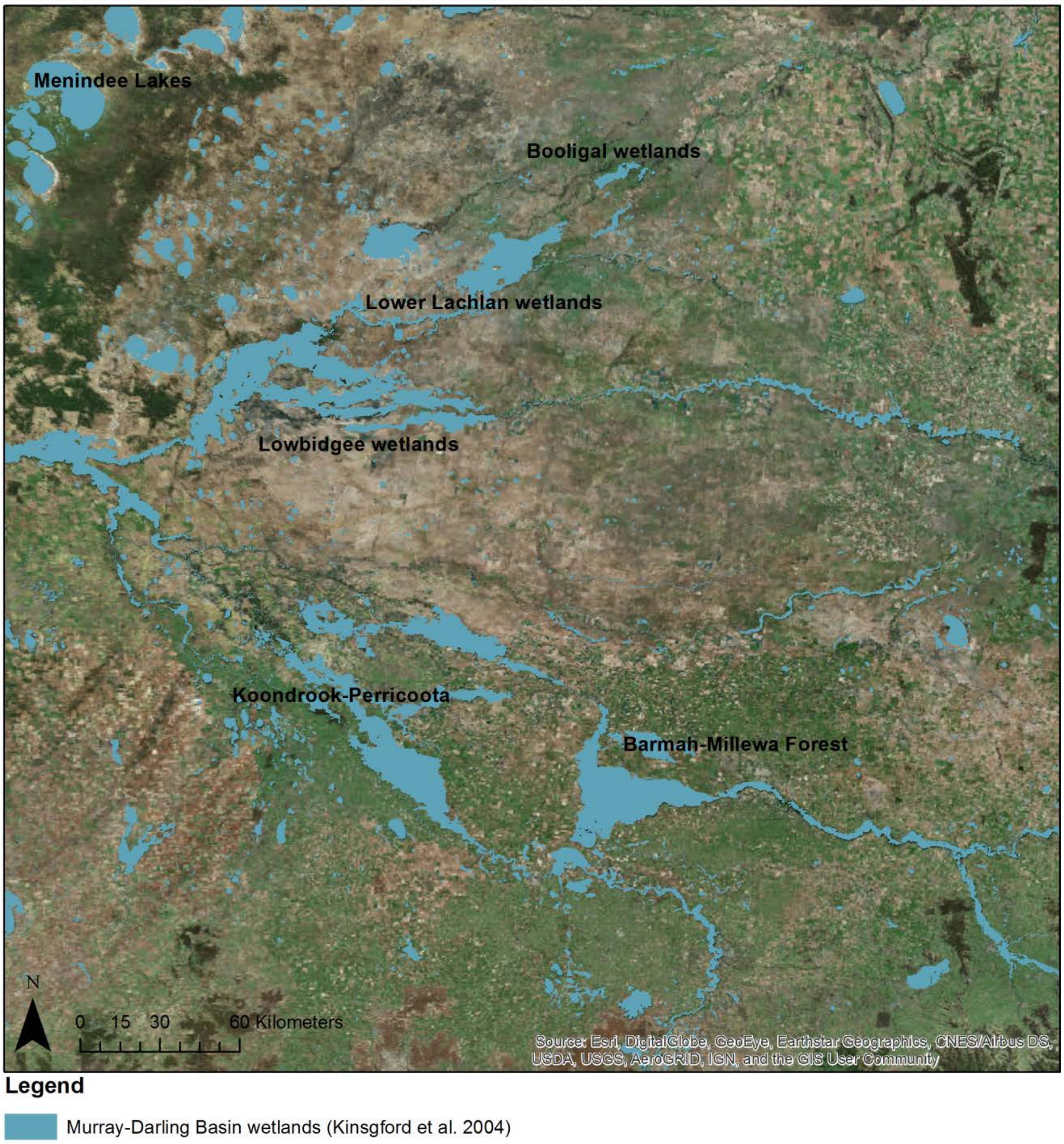


Figure 20 Wetlands in the region of the Lower Lachlan wetlands, including Booligal Wetlands.

Statistical analyses

The updated statistical models continue to support the findings of Driver et al. (2005).with total number of daily flows greater than 2,500ML having the largest effect size and providing the best fit model with breeding events. In addition to this, statistical analyses also found that the probability of breeding occurring were maximised when there was ~100 days of flows >2,500 ML or when total flow volumes were 500 GL.

Conclusion

While the non-breeding by ibis in 2015 was probably attributable to a combination of events; high temperatures and rapid drying of vegetation in conjunction with relatively low flow volumes (associated with ibis breeding) and rapid drops in river flows. The only management tool that may have altered the outcome would have been to increase flow volumes to those associated with ibis breeding (2,500 ML/day at Booligal). However there is no guarantee that increased flows alone would have resulted in breeding.

Colonial waterbird breeding has three broad requirements; 1) sufficient water resources, including flow volumes, flow duration, and water levels at the colony site. 2) nesting materials, suitable structural vegetation is required for the building and placement of nests, and 3) food resources. Sufficient food resources are required to support adults and young throughout the breeding period.

The interrelatedness of a specific set of hydrological requirements, adequate food resources and suitable nesting habitat, in addition to landscape scale variables and decisions made by birds makes it difficult to guarantee a desired outcome through flow management. No one component will result in successful breeding, but rather the combination of all factors.

Managing for a successful breeding event at a wetland cannot be guaranteed but can be optimised using the tools available. Management tools currently available can manage for two out of the three requirements. Hydrological management is central to both – flows can be managed to meet targets set to support waterbird breeding events, and flows can be managed to maintain wetland vegetation communities that provide the nesting resources when breeding occurs. This includes key vegetation types such as lignum, phragmites and floodplain eucalypt communities. Maintenance of wetland habitat between waterbird breeding events also ensures ecosystem functioning and the food web structures so that when breeding does occur the food web is able to support the food resource demands of the waterbirds.

The management of food resources, particularly for species that feed outside the wetland (e.g. ibis) is beyond the scope of current tools available to managers. However for species that feed within the wetland, such as spoonbills, cormorants, and egrets, the maintenance of food web structures and ecosystem functioning may provide the tool for managing food resources. This would include the maintenance of the wetland vegetation (see Roberts et al. 2000; Roberts and Marston 2000; Casanova 2015), invertebrate communities (see Boulton and Lloyd 1992), frog (O'cock et al. 2014) and fish communities (see King 2009; King et al. 2009). Each of these ecosystem components have their own specific wetting and drying regimes required to maintain functional communities and populations. Similarly they all respond to wetting and drying at different temporal and spatial scales (Kingsford et al. 2005).

As previously discussed, breeding does occur when flow conditions are sub-optimal, however the success of these events has generally been poor (Magrath et al. 1991; Brandis et al. 2010). The provision of supplementary 'top-up' flows to colonies which have established during sub-optimal flow conditions is an option available to water managers. There are both potential positive and negative outcomes. Positive outcomes include improving the sub-optimal conditions to more optimal, for example if ibis initiated nesting on lower than expected flow thresholds then the provision of more water may provide conditions more commonly associated with successful breeding events, and thereby providing a greater change of breeding success (than it may otherwise have been if breeding continued on sub-optimal flow conditions). Additional positive outcomes may include providing opportunities for fish and frog spawning and longer duration inundation of floodplain vegetation communities. Potential negative outcomes may involve the delivery of water for no measureable increase in breeding success. This situation may arise if the delivery of top-up flows is too late and birds have already begun to desert the colony.

In summary this report found that insufficient flow volumes with rapid drops in river flow coupled with unseasonally high temperatures contributed to ibis deciding not to breed in the Booligal Wetlands in 2015. Water management options at the time may have included supplementary flows, although this would have involved risks. The greatest risk associated with supporting breeding that has initiated on sub-optimal flow conditions is that there is no improved success as a result. Colony desertion may occur for number of reasons including falling water levels, cold weather and/or poor food resources.

Research gaps

A persistent knowledge gap that requires research is natal site fidelity. As discussed previously there is evidence in the international literature that some species exhibit natal site fidelity. However, for Australian species the extent to which natal site fidelity plays a role in habitat use is unknown.

An additional knowledge gap specific to the Lachlan is the lack of detailed modelling of flow thresholds for waterbird breeding. Driver et al. (2005) identified flow thresholds at Booligal, however there is a need to improve understanding of the flow volumes required on Merrimajeel Creek for colonial waterbird breeding, and to update the Booligal models with recent data and modelling techniques. This type of detailed modelling has been done successfully for the Narran Lakes (Brandis and Bino 2016, Merritt et al. 2016) and is used to inform the setting of water management targets (MDBA 2012).

Acknowledgments

This desktop review relies heavily upon observations made in the field during August – November 2015. These observations were made by staff from NSW Office for Environment and Heritage (Jenny Spencer, Jo O’cock, Paul Packard, James Dyer, Carmen Amos) Commonwealth Environmental Water Office (Erin Lenon), the Centre for Ecosystem Science, UNSW (Richard Kingsford) and the University of Canberra (Fiona Dyer).

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Appendix 1 Historical flow records and ibis breeding

Table 1 shows periods of flow where total daily flows exceed 2,500 ML (start and end dates), the number of continuous days flow exceeded 2,500 ML, and the maximum daily flow recorded during that period. Flow events have been numbered to show that some periods where flow exceeded 2,500 ML may have been part of a larger single flood event, for example event number 2. There were two periods where flows exceeded 2,500 ML for multiple days, but these periods were within the context of a single longer duration flood event.

Table 1 Historical flow records for period of >2,500 ML total daily flow. Grey shaded rows identify flow events that had associated ibis breeding.

Start date	End date	Mean daily total flow (ML)	No. of days >2,500 ML	Max. daily flow volume (ML)	Event no.
18/09/1909	30/09/1909	2891	13	3230	1
4/09/1912	10/09/1912	2606	7	2708	2
18/09/1912	12/12/1912	3153	25	3545	2
15/08/1915	18/08/1915	2500	4	2500	3
24/08/1915	15/09/1915	3288	23	3765	3
18/07/2016	21/01/1917	3948	188*	4489	4
15/08/1917	30/12/1917	3952	138*	4856	5
8/09/1918	3/10/1918	3395	26	3689	6
7/09/1920	27/10/1920	3710	51*	4122	7
21/01/1921^	16/01/1921	2641	5	2708	8
29/07/1921	1/08/1921	2591	4	2622	9
25/08/1921	21/09/1921	3404	28	3875	10
20/08/1922	18/09/1922	3404	30	3875	11
31/07/1923	20/09/1923	3684	52*	3943	12
27/09/1923	13/11/1923	3321	48	3689	12
22/07/1925	4/09/1925	3317	45	3765	13
14/09/1925	24/09/1925	3797	11	2970	13
31/05/1926	12/11/1926	3466	166*	4014	14
16/03/1928^	30/03/1928	2796	15	3024	15
3/05/1928^	7/05/1928	2589	5	2622	16
20/07/1928	25/07/1928	2520	6	2539	17
11/08/1928	10/09/1928	3391	31	3545	18
15/06/1931	1/11/1931	4199	140*	4917	19
6/12/1934	8/12/1934	2500	3	2500	20
7/09/1936	23/09/1936	2802	17	2935	21
4/09/1943	14/11/1943	2996	72*	3342	22

27/01/1948^	2/02/1948	2592	4	2730	23
20/07/1948	31/07/1948	3934	12	3156	24
22/04/1950	22/01/1951	3876	276*	4408	25
22/07/1951	26/11/1951	3457	128*	4101	26
24/05/1952	14/12/1952	4023	205*	4581	27
3/02/1953^	6/02/1953	2531	4	2553	28
6/09/1955	17/10/1955	3089	42	3390	29
9/11/1955	31/12/1955	2876	53*	3157	29
23/03/1956	**10/01/1957**	**4565**	**294***	**7337**	**30**
10/11/1958	21/11/1958	2711	12	2837	31
6/04/1959^	24/05/1959	2948	49	3242	32
17/08/1959	17/09/1959	3243	32	3498	33
24/11/1959	29/11/1959	2537	6	2548	34
23/08/1960	1/12/1960	3403	101*	3657	35
11/09/1961	14/10/1961	3031	34	3280	36
19/12/1961	17/01/1962	2861	30	3060	37
14/02/1962^	6/03/1962	2807	21	3012	38
18/09/1962	30/09/1962	2877	13	3105	39
3/07/1963	16/07/1963	2902	14	3189	40
30/07/1963	13/11/1963	3601	107*	3856	40
29/08/1964	31/08/1964	2523	3	2526	41
21/09/1964	12/12/1964	3367	83*	3606	41
20/06/1969	1/11/1969	2982	135*	3279	42
20/11/1969	27/11/1969	2706	38	2837	42
22/10/1970	26/11/1970	2746	36	2857	43
14/05/1974	1/01/1975	3688	233*	4619	44
5/10/1975	17/12/1975	2847	74*	3222	45
23/02/1976	18/04/1976	2881	56*	3011	46
2/11/1976	13/12/1976	3052	42	3165	47
4/07/1978	16/11/1978	3463	136*	3701	48
30/08/1984	29/11/1984	3320	92*	3728	49
4/12/1984	7/12/1984	2523	4	2535	49
26/10/1988	4/11/1988	2704	10	2826	50
10/05/1989	11/10/1989	3500	155*	3786	51
25/05/1990	26/11/1990	4094	186*	5001	52
7/10/1991	26/10/1991	2670	20	2859	53
30/10/1992	12/12/1992	2840	53*	3122	54
23/01/1993^	31/01/1993	2721	9	2853	54
9/09/1993	14/09/1993	2570	6	2602	55
2/10/1993	2/12/1993	3263	62*	3459	55

17/12/1993	26/12/1993	2678	10	2737	55
14/11/1996	1/12/1996	2820	18	2946	56
27/08/1998	30/08/1998	2525	4	2544	57
2/09/1998	29/11/1998	3295	89*	3716	57
19/09/2000	16/10/2000	2805	28	3041	58
19/01/2011^	29/01/2011	2561	11	2586	59
5/04/2012^	9/06/2012	2898	66*	3090	60
23/07/2012	23/08/2012	2653	32	2834	60

*denote that the flow duration exceeded 50 days.

^timing of flow was not in, or did not include the optimal period of June-November.

Appendix 2 Background on Booligal Nesting Event October-November 2015

Prepared by Paul Packard and Jennifer Spencer, NSW OEH (26 April 2016)

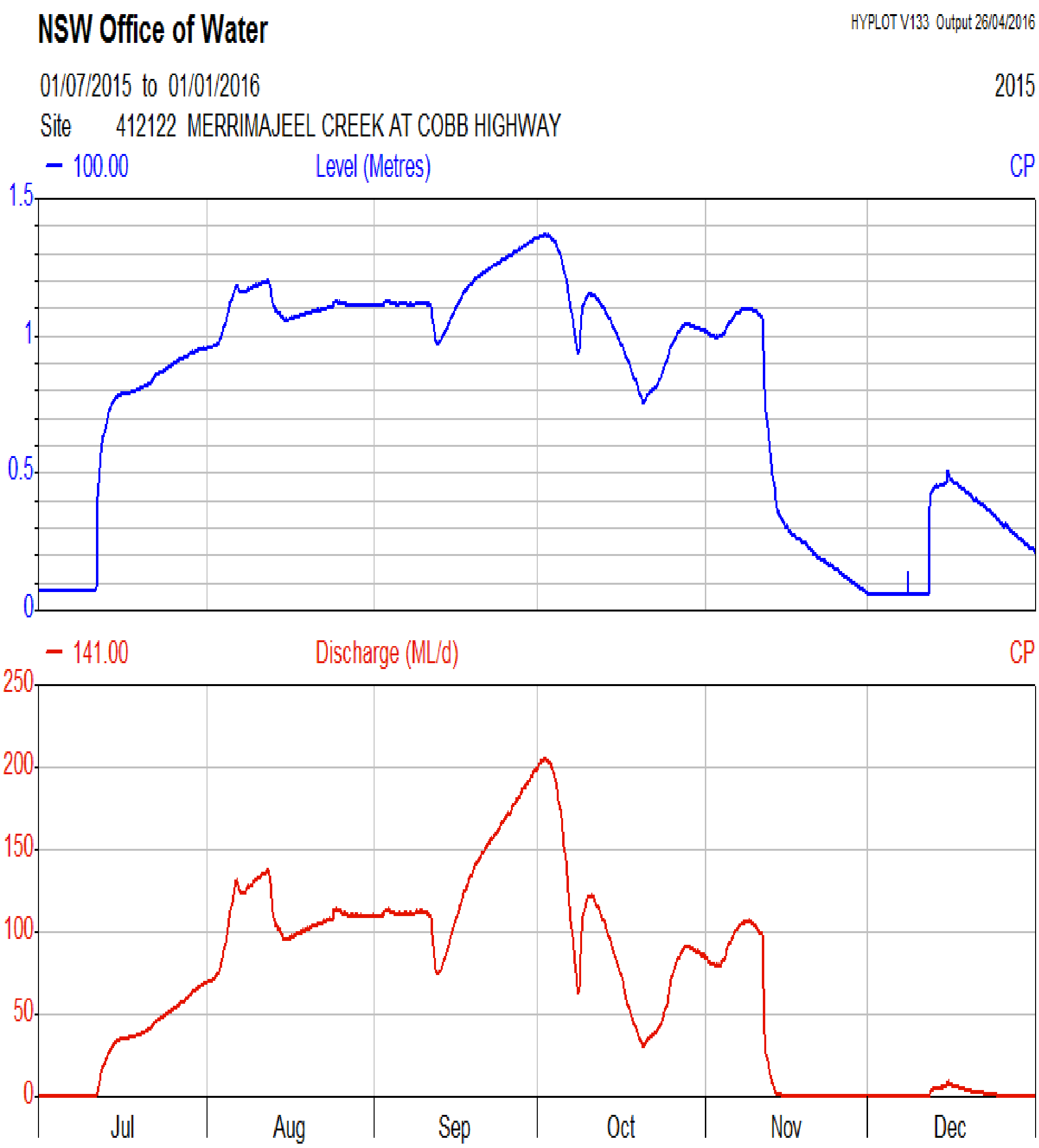
The Booligal/lower Lachlan area received good rainfalls in autumn 2015, although conditions turned drier in winter. There were continuous flows into the Merrimajeel Creek from commencement of the stock and domestic replenishment flow in mid-July 2015, followed by a delivery of environmental water targeting Murrumbidgil Swamp (Figure 1). In September 2015 a translucent environmental flow entered the creek and contributed to wider inundation of the Booligal wetland system.

Following the conclusion of the translucent flow environmental flows were resumed into the creek to complete the delivery to Murrumbidgil Swamp that was suspended during the passage of the translucent flow. Operational constraints relating to installing and removing boards from the Torriganny Weir (requires a contractor from Hay to come out with a crane) resulted in there being short but significant drops in creek flows immediately prior to commencement of the translucent flows into the creek and again at the conclusion of the translucent flow before levels in the Torriganny Weir could be built up again to resume delivery of the environmental water.

Over the course of late September and into October 2015 there were consistently reported observations by locals that ibis numbers were building up in the lower Lachlan area generally and in the area of the Booligal wetland in particular. On 16/10/15 whilst at the Block bank regulator Jim Crossley observed >1,000 straw necked ibis in groups of approx. 100 flying low and landing upstream of the block bank in the area of the core nesting site (on Lachlan Valley SCA/Booligal Station). Mr Crossley also observed several small groups of glossy ibis flying low in the area. To reduce the risk of rapid falls in the water levels at the breeding site that could lead to abandonment of what may have been a breeding event in its early stages Mr Crossley was advised by Paul Packard to install three boards in the Block bank regulator. At that time water level at the Block was 86cm and trending downwards. Boarding the regulator was intended to stabilise water levels given that there was a "hole" in the creek arriving at the time. The regulator setting was also intended to achieve a water level at the nesting site within the range that had occurred recently and that could be sustained with an achievable arriving flow of 45-55ML/D. Following installation of boards water levels at the Block bank initially rose for several days (peak 91cm) before declining back to just below their level of the 16/10/15 before rising again and stabilising around 93cm.

The Booligal area experienced hotter than average conditions combined with below average rainfall during October. While straw necked ibis continued to be reported in the region, from approximately 20/10/15 onwards there was a trend of fewer reports by local landholders and observers of any large groups of ibis congregating in the Booligal area.

A site inspection was undertaken on 28 October 2015 by Paul Packard and Carmen Amos of NSW OEH. The nesting site including the main nesting area used in previous years (Figure 2, Plates 1-2) on Lachlan Valley State Conservation Area -Booligal Station was surveyed soon after sunrise by Argo amphibious vehicle. No straw-necked ibis were observed on the ground or in the air although there was evidence that recent trampling had occurred in the core area of the site. There was no evidence of any actual nest construction in the areas subject to recent trampling (see Plate 3).



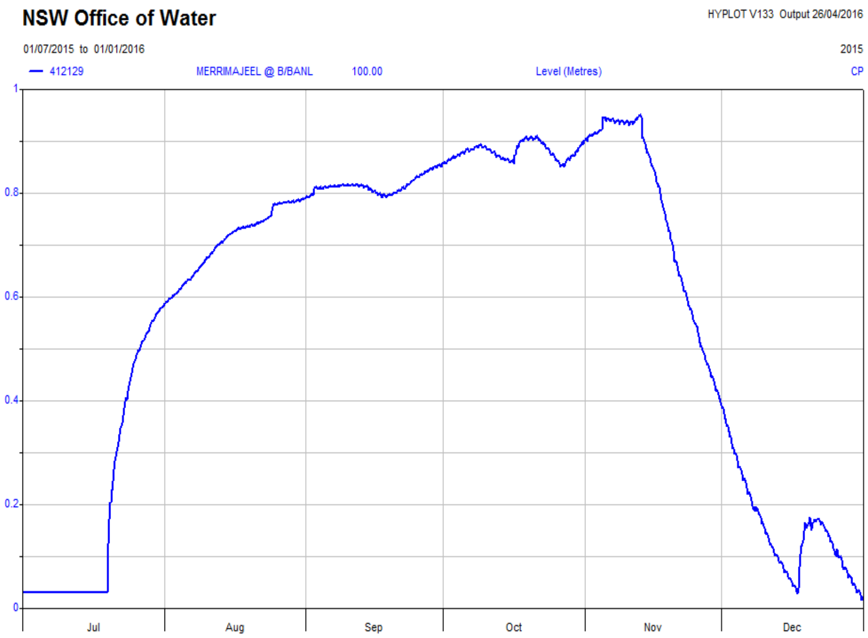


Figure 1 Discharge (ML/d) and water levels (m) at the Merrimajeel Creek @ Cobb Highway (GS41222) (upper) and Merrimajeel Creek @ B/Bank (GS412129) from NSW WaterInfo.

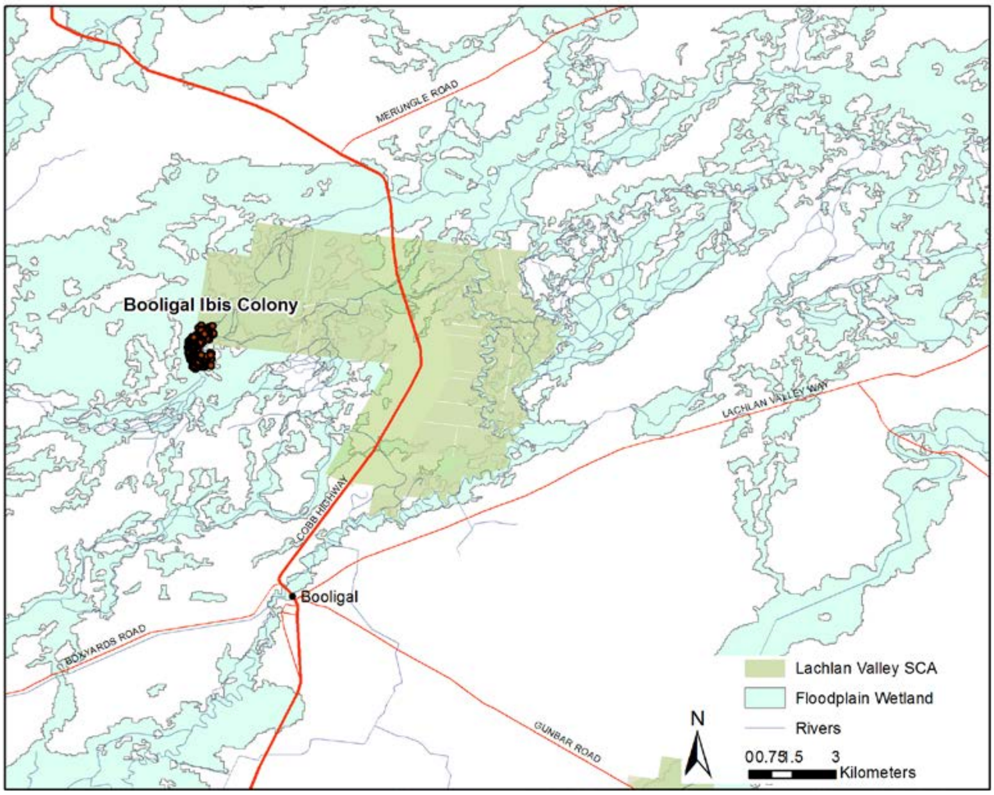


Figure 2 Location of active nests during the 2010-11 breeding event when straw-necked ibis nested in Booligal Wetlands on the edge of the Lachlan Valley State Conservation Area.

Water orders were made to keep flows going until 17 November 2015 in case there was a later attempt by birds to establish a colony. Following a flyover on 9 November 2015 Richard Kingsford (UNSW) reported hundreds of straw-necked ibis feeding in both the Lowbidgee and Lower Lachlan but no nesting/trampling activity, while there were small numbers of Australian white ibis thought to be nesting in the Cumbung Swamp (Plate 4). Based on this advice the Merrimajeel regulator was closed on the 10 November 2015 and the boards in the block bank regulator were taken out on 13 November 2015. Following the decision on 10 November to close the Merrimajeel Ck regulator the last seven days of releases made for the Merrimajeel/Booligal ibis site, and which were already on the way down the Lachlan/Torriganny, were directed instead into the Muggabah Creek.

A further aerial survey on 25 November 2015 of the Lower Murrumbidgee and Lower Lachlan by Paul Packard, Joanne O'cock and James Dyer (NSW OEH) confirmed no active nesting in the Lower Lachlan. Although there were flocks of pelicans, Australian white ibis, Yellow spoonbills and Stilts feeding in the Great Cumbung where flows were still occurring (Plate 4).

Plate 1: Booligal ibis nesting site on Lachlan Valley State Conservation Area (looking west) on 18/8/15 (Paul Packard, NSW OEH).

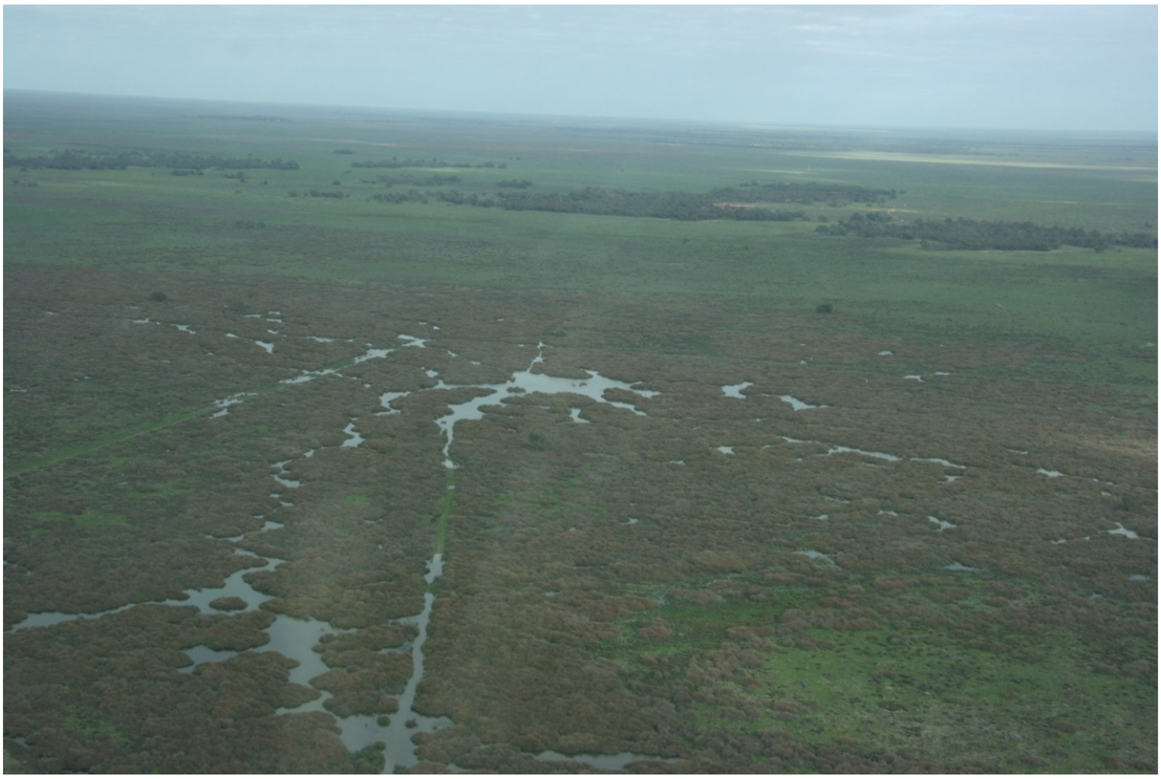


Plate 2: Booligal Swamp ibis nesting site on Lachlan Valley State Conservation Area (looking west) on 18/8/15 (Paul Packard, NSW OEH).

Plate 3: Trampled lignum in core of nesting site in Booligal Swamp on 28/10/15 (Credit: Paul Packard, NSW OEH).

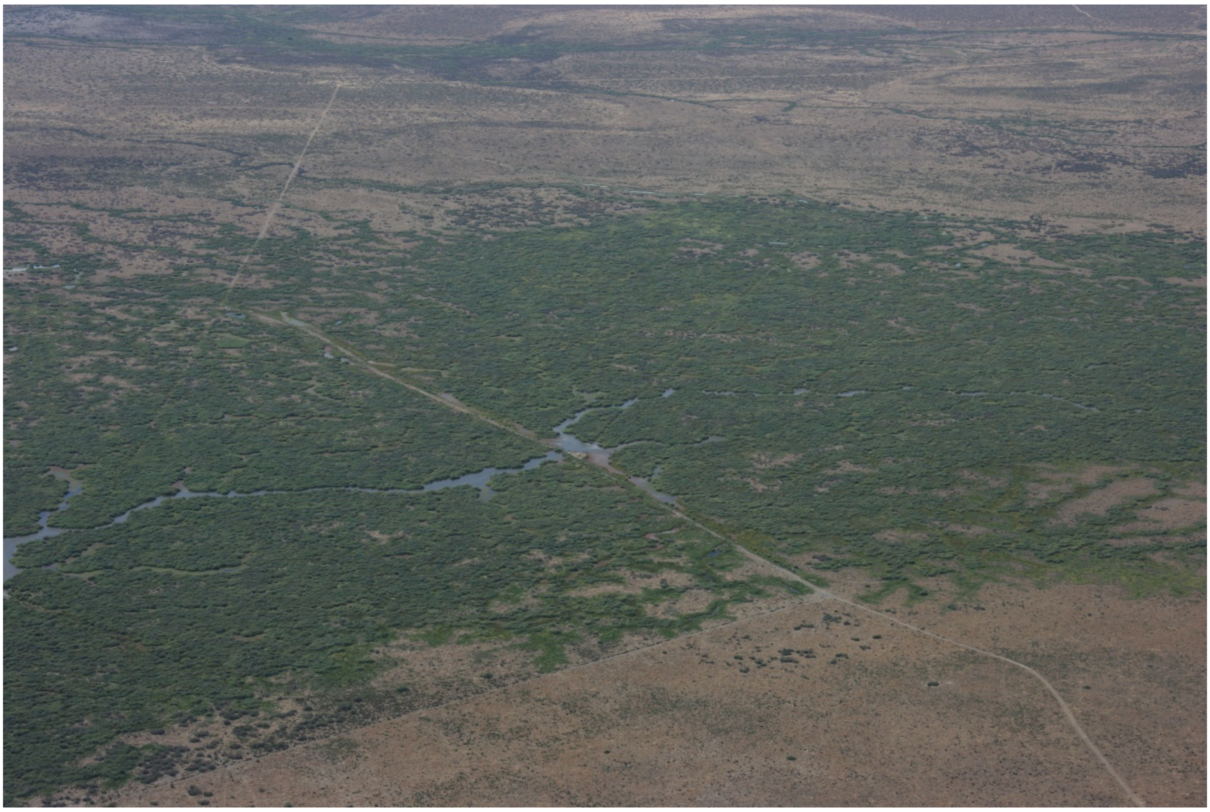


Plate 4: Booligal Swamp (25 November 2015) (Credit Paul Packard, NSW OEH).

Appendix 3 Vegetation condition Lachlan Catchment May-November 2015

Dr Fiona Dyer, Vegetation team leader, Long Term Intervention Monitoring Program.
Personal observations

In May 2015, the catchment was dry and there was little change in the vegetation condition from previous dry conditions. Ground cover was dominated by terrestrial species and recent rains saw a flush of germinants on all of our sites but no noticeable change in vegetation condition.

In September, the catchment had received good rains which had filled storages and triggered translucent flows. There was water everywhere – roadside drains, depressions and in the river. The vegetation was flush and flowering – just a carpet of flowers at Willandra National Park (Figure 1). Birds were everywhere and I was particularly interested to see that the smaller birds were everywhere (and had been missing for the past 2 years I'd been doing a field class there).

Then when I was out surveying in October/November, the catchment was hot – unseasonally so I thought. There was evidence of lots of vegetation on our plots, but by then, most had 'burned off' and was dead. There was still water in the channels and wetlands and it was green in the immediate vicinity of the channels and wetlands.

Figure 1 Flowering grassland community at Willandra following widespread rainfall in the catchment (Photo: Fiona Dyer, Sept. 2015